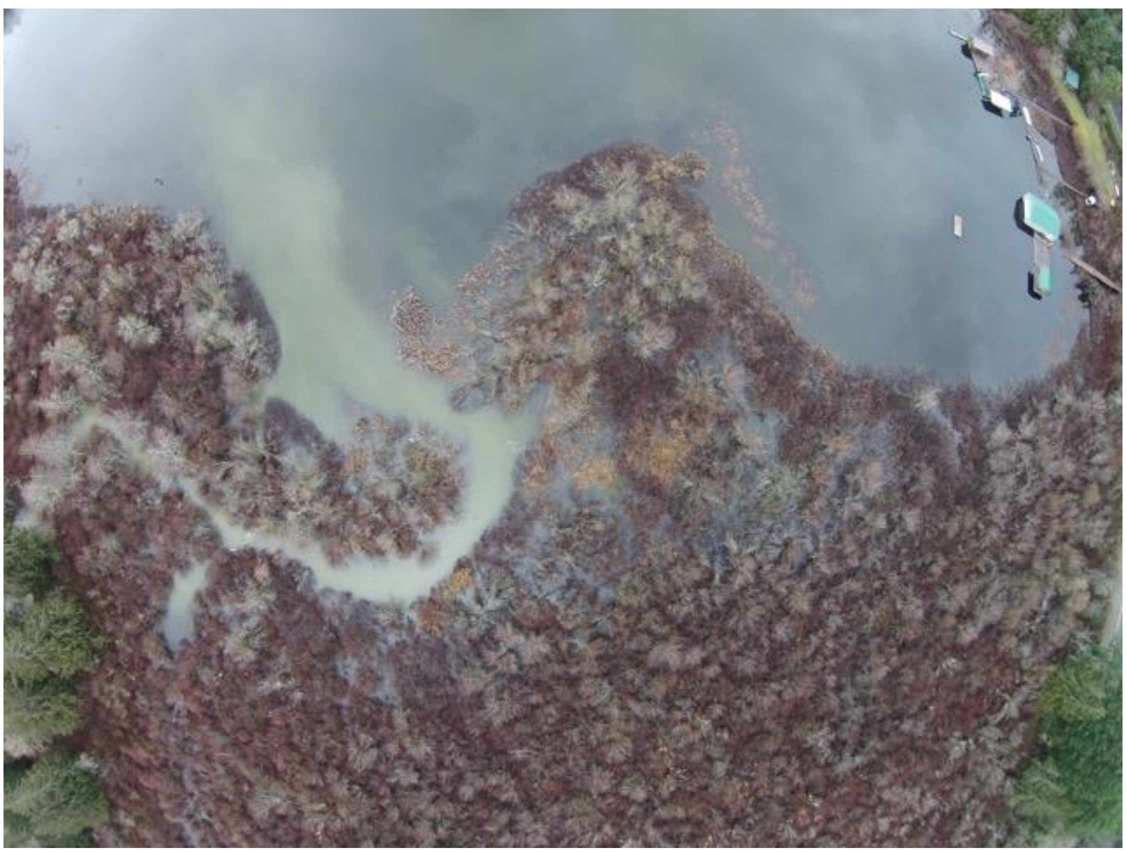
Shawnigan Lake 2020 Water Quality Report: Including Attainment of the Water Quality Objectives

by

L. Gregory, D. Munday, B. Juurlink, and C. Evans

Shawnigan Basin Society



Acknowledgements

The authors would like to recognize the assistance received to accomplish the Shawnigan Lake water sampling program and the associated program for inlet and outlet streams in the watershed. The Cowichan Valley Regional District (CVRD) provided funding through the Area B grant-in-aid program administered by our Area B Director Sierra Acton. The funding was provided to the Shawnigan Residents Association who administered the funding for the programs. Volunteer assistance was organized through the Shawnigan Basin Society (SBS) and included the following individuals – Dr. Ralph Turner and Dave Munday conducted lake sampling and sample transfer. Bernie Juurlink, Linda Gregory, Ed Wiebe, Cliff Evans, Shelagh Bell-Irving, and Dave Hutchinson assisted with stream sampling.

The authors are grateful to Rosie Barlak, Environmental Impact Assessment Biologist – BC Ministry of Environment and Climate Change Strategy (ENV), who continues to assist with documenting the results of these studies properly in the Provincial Environmental Management System (EMS).

Cover Photograph:

South Shawnigan Lake, January 17, 2016; Photograph by Russell Robertson

Citation:

Gregory, L., D. Munday, B. Juurlink, and C. Evans. 2021. Shawnigan Lake Water Quality Report: Including Attainment of the Water Quality Objectives. Shawnigan Basin Society, 1760 Shawnigan-Mill Bay Road, #102. V0R2W0.

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Executive Summary

Rieberger (2007) established Water Quality Objectives (WQO) for Shawnigan Lake which included parameters and recommended sampling times, lake sites and depths. The parameters are dissolved oxygen, Secchi depth, total phosphorus, total nitrogen, N:P ratio, turbidity, total organic carbon and chlorophyll *a*. There are also WQO for microbiological indicators *Escherichia coli*, *Enterococci* and fecal coliforms. There are four lake sites. We moved one station so that it is at the first deep basin at the south end and thus closer to the incoming stream. The sampling times require monthly and yearly means, growing periods, and different depths. For this study, samples were collected in March and September 2020, which obviated obtaining monthly and annual means and no growing period information. The comparison of the WQOs is thus to the data collected. We did not obtain samples for microbiological indicators, but did include broad spectrum of total and dissolved metals and included temperature and pH in our discussion.

Several parameters did not meet the WQOs. These were primarily in the bottom samples in the South Basin and West Arm. Sediment plumes from the creek at the south end are visible after heavy rainfall events and there is an input stream to the more shallow West Arm. How these inputs, the dense mats of Eurasian watermilfoil and general lake productivity affect the water quality is discussed. The concentration of total manganese exceeded the aesthetic concentration in the bottom sample from September in all of the sites and the maximum acceptable concentration for drinking water in the bottom sample from September at three of the sites.

Recommendations for future sampling programs and analyses are given.

1. Introduction

As explained by Javorski and Barlak (2020), the Province of British Columbia Ministry of Environment and Climate Change Strategy (ENV) has a mandate to protect water bodies, and as part of this mandate water quality assessments and Water Quality Objective (WQO) reports have been prepared for numerous lakes, rivers, and marine surface waters. The WQOs are based on the specific conditions of the water body: water quality, water movement, waste discharges, and water uses and their associated guidelines. For most parameters, reports were completed by the BC Ministry of Environment (now ENV) that summarized pertinent literature in order to recommend a water quality guideline for different water uses. Because each water body is different, the WQO may be less than the water quality guideline. The WQOs currently have no legal standing, but can direct resource managers charged with protecting the water quality of a water body and are used to measure any changes in the water quality over time. For example, this science-based information and any trends that are identified can help inform local governments on water quality targets and monitoring when developing plans for drinking water, liquid waste and land use.

A second and important component of these WQOs is attainment monitoring and reports. These are undertaken every three to five years with the goal of determining whether the WQOs are being met and whether there are any trends in changes in the water quality. This is an attainment report.

Although not part of the Water Quality Objectives or included in previous attainment reports is information on the presence of the invasive aquatic plant *Mryiophyllum spicatum* (Eurasian watermilfoil) in Shawnigan Lake. It was first reported in Shawnigan Lake in the 1970's and was recognized as a concern in 2016 when M. Martinez and K. Musselwhite of the Shawnigan Basin Society (SBS) first mapped the presence of Eurasian watermilfoil (http://www.shawniganbasinsociety.org/milfoil.html.). Williams et *al* (2018, also called the Madrone Report) summarized the general life history of the plant, outlined existing control – mechanical, chemical, and biological – methods and made suggestions about management of *M. Spicatum* in Shawnigan Lake. Another control measure – the use of high oxygen content (96%) nano-bubbles was suggested by Gaia Water Ltd., but it use was unsuccessful as determined in the summer of 2019 after monitoring over a ten-week period at three sites where private citizens had nanobubbler systems installed (B. Juurlink, pers. comm.). In 2019 and in 2020, the Shawnigan Residents Association (SRA) organized campaigns to have the residents safely remove the Eurasian watermilfoil. The attempts had some local success, but also failures with numerous fragments released and the *M. spicatum* is still present in dense populations in the shallow – up to 10 m – waters of much of the lake. The death and decomposition of this plant can have effects on the water quality of the lake and therefore is addressed in this report.

On April 21, ENV issued Permit 105809 to allow South Island Aggregates to dump 10 million tonnes of contaminated soil in a quarry on Lot 23 situated within the Shawnigan

Creek watershed. This created a lot of public protest and several court cases. Because of protests, appeals to the Environmental Appeal Board and court cases by the CVRD and the Shawnigan Residents Association, only 100,000 tonnes of contaminated soil was deposited into the landfill before the Permit was cancelled on February 23, 2017. Most of the contaminated soil was dredgeate with the major contaminants being sodium and chloride ions. The Ministry approved the Final Closure Plan on June 26, 2019. The Final Closure Plan has been completed in the Fall of 2020. Post-closure monitoring of a number of monitoring wells as well as the Ephemeral Stream will be performed over the next 30 years. There is evidence that the contaminated soil landfill is leaking; however, with the major contaminants being sodium and chloride ions and the total mass of the contaminated soil being 100,000 tonnes rather than the 10 million tonnes allowed by the permit, it is not likely that the contaminated soil landfill will have a major impact on the watershed. The protest efforts of the citizenry of South Cowichan prevented a major catastrophe in the Shawnigan Creek watershed. Because of the residents concerns of metals entering the lake, a series of metals were sampled in the lake waters.

Appendix IV is a more detailed summary of the history of the contaminated soil landfill.

2. Sampling and Analytical Methods

2.1 Sample Station Locations

Water quality sample stations include three of four stations from Rieberger (2007). The South Basin station (L2) has been changed to the basin that is in line with the inflow from South Shawnigan Creek. The station locations relative to the Provincial Environmental Management System (EMS) is as follows:

L1	North Basin	EMS 1199901
L2	South Basin	EMS E315291
L3	West Arm	EMS 1199903
L4	North Beach	EMS 1199904

Shawnigan Lake sample station locations are shown in Figure 1.

2.2 Lake Profiles

Vertical profiles were taken at each lake station using a YSI ProDSS water quality profiler complete with a 60-meter cable rented from Hoskin Scientific Ltd. Parameters included:

- Depth (m)
- Temperature (degrees Celsius)
- Dissolved Oxygen (mg/L and % saturation)
- Specific Conductance (µS/cm)
- pH
- Turbidity (Nephelometric Turbidity Units or NTU)

Figure 1.

Although the sampler was equipped with a depth sensor, the sampler was deployed using a metered line to confirm target depths (m).

The WQ profiler used for the sampling program was rented from a scientific equipment supplier and was factory calibrated, which included a calibration check upon return.

2.3 Water Samples for Laboratory Analysis

Water samples were taken at each lake sample station. Water sampling employed a 12-volt marine diaphragm pump and C-flex tubing with a plastic-coated weight attached to the intake end. This sampling system was deployed from a vessel anchored in position. Samples were taken approximately 1.0 meter below the surface (top samples) and within two meters of the bottom (bottom samples). Water depths at sample stations were determined using a Lowrance X-18 digital sounder. The pump and tubing were first flushed for at least one minute with water from the target sampling depth. Sample bottles were supplied by the analytical laboratory and were pre-cleaned and ready for use. Samples for physical tests, anions, nutrients, total metals, and total mercury were filled with unfiltered water from a short piece of C-flex tubing attached to the pump discharge. The pump was then shut off briefly to allow installation of an inline filter (0.45 µM pore size). The pump was restarted, and the filter flushed with ~3x filter volumes (500 mL) before filling sample bottles for dissolved metals and dissolved mercury.

Samples were held in coolers complete with freezer packs and delivered on the day of collection to the ALS depot in Victoria, BC.

2.4 Chlorophyll *a* For Laboratory Analysis

Chlorophyll *a* sampled were filtered in the field using a plastic filtration apparatus including a filter funnel and base. The base is attached to an evacuation pump to promote flow from the upper chamber through the filter. Membrane filters (0.45 µm porosity x 47mm diameter) were used to retain the chlorophyll bearing material. The upper chamber volume was 150 ml, and the chamber was filled twice so that the total filtered volume was 300 ml. Once the filtering process was completed, the filter papers were extracted with forceps and place in laboratory supplied black sample tubes with sealed lids. The tubes containing samples were frozen and subsequently included with lake water samples to be transported to the ALS depot in Victoria.

2.5 Secchi Depth

Secchi depths were determined using a standard 20 cm Secchi disk deployed on a waterproof metered tape. The depth at which the disk can no longer be seen is the Secchi depth. Care was taken to avoid glare on the water and wave action, both of which can interfere with Secchi depth measurement.

2.6 Sampling Dates

The first sampling event was in March, 2020. On March 9, 2020, all four lake sampling locations were sampled for vertical profiles using the YSI ProDSS meter. Chlorophyll *a* samples and Secchi depth measurements were also sampled. On March 10, 2020, water samples were collected at all lake stations. Samples were delivered to the ALS depot in Victoria that same day.

The second sampling event was in September, 2020. On September 23, 2020, all lake stations were sampled for vertical profiles using the YSI ProDSS meter. Chlorophyll *a* samples were collected and Secchi depths were measured. On September 25, 2020, water samples were collected at all lake stations and delivered that same day to the ALS depot in Victoria for subsequent analysis.

2.7 Sample Transfer and Documentation

All samples for laboratory analysis were document using Chain of Custody (COC) forms. These forms described the samples that were included and specified the time of sampling and the required analyses. The laboratory provided Sample Receipt Notifications (SNRs) which identified issues associated with the samples or shipment temperatures, if any. The results of the analytical process were later provided as a Certificate of Analysis. The laboratory also provided a Quality Control Interpretive Report to document any irregularities during the analytical process.

2.8 Sample Results

All of the raw data are given in the Appendices and the ALS QA/QC information are uploaded to Google Drive.
https://drive.google.com/drive/folders/1wBvqh6kW5str5iDq8bn9t1n0XF3_xYSa?usp=sharing.
Specific parameters are discussed in the next section.

3. Attainment Objectives and Results

Rieberger (2007) using the data collected in two previous studies (Nordin and McKean, 1984; Rieberger et al., 2004) developed WQOs for Shawnigan Lake. They are given in Table 1. This report discusses each of the parameters. However, the report is based on only two sample times (March and September) and thus only one at spring turnover and no growing period (May - August). Also, there are two types of samples: those using the YSI multi-parameter instrument at different depths and grab samples from the top and bottom (see Sampling and Analytical Methods) and thus objectives which require an annual mean are not possible (e.g., Secchi Depth) so the data discussed as collected. It also means that there was no mid-depth sample at sites L1 (North Basin) and L2 (South Basin) to get a mean for total phosphorus and total nitrogen so again the data are discussed as collected. The required objectives and the data used in this report are explained with each parameter. It should be noted that temperature and pH are not contained in the objectives, but do have BC Guidelines; this is also the case for the total and dissolved metals.

Table 1. Water Quality Objectives for Shawnigan lake. From Javorski and Barlak (2020), with permission.

Site	**1199901**	**1199902**	**1199903**	**1199904**	**E257436**	**E257437**
Designated Water Uses	Drinking water, recreation (primary contact), aquatic life					
Characteristics						
Dissolved Oxygen[1]	≥ 5 mg/L					
Secchi Depth[2]	≥ 5 m					
Total Phosphorus[3]	≤ 8 µg/L at spring overturn					
Total Nitrogen[4]	≤ 250 µg/L					
N:P Ratio[5]	≥ 30:1					
Turbidity[6]			≤ 1 NTU			
Total Organic Carbon	≤ 4 mg/L					
Chlorophyll-*a* [7]	≤ 2 µg/L					
Escherichia coli [8]			≤ 10 CFU/100 mL (90th percentile)			
Enterococci[8]			≤ 3 CFU/100 mL (90th percentile)			
Fecal Coliforms[8]			≤ 10 CFU/100 mL (90th percentile)			

1 This objective applies to any depth of the water column throughout the year.

2 Annual mean.

3 This objective applies to the average of at least three samples taken throughout the water column (surface, mid depth, one metre above bottom) for sites 1199901 and 1199902 and to the average of at least two samples (surface and one metre above bottom) for sites 1199903 and 1199904.

4 This objective applies to the average of at least three samples taken throughout the water column (surface, mid depth, one metre above bottom) for sites 1199901 and 1199902 and to the average of at least two samples (surface and one metre above bottom) for sites 1199903 and 1199904, at spring overturn.

5 The N:P ratio is calculated using average total nitrogen and total phosphorus concentrations.

6 This objective applies to any grab sample taken within 10 m of a domestic water intake (E257436 and E257437). It also applies to sites 1199903 and 1199904 which likely reflect conditions near domestic intakes on the lake.

7 Values are to be growing season averages for epilimnetic water in the main basin of the lake.

8 The 90th percentiles are calculated from at least five weekly samples collected in a period of 30 days. For values recorded as <1, a value of 0 should be used to calculate the statistic. If any of the objectives are exceeded, further sampling should be conducted during the summer low flow and fall freshet periods, consisting of at least 5 weekly samples in a 30-day period.

3.1 Temperature

There is no water quality objective for temperature in Shawnigan Lake. However, the BC Approved Water Quality Guidelines give an aesthetic guideline for drinking water of 15^{o} C (https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines). This is based on the extensive literature review by Oliver and Fidler (2001) that includes a summary of factors that determine ambient water temperature, and guidelines that provide protection for all beneficial uses. Also, included in Oliver and Fidler (2001) is a detailed review of the literature on temperatures that provide protection for aquatic life with an emphasis on the different life stages of salmonids. As there is no one temperature, for the protection all stages of development of salmonids, Oliver and Fidler (2001) include several tables giving optimum and threshold temperatures for different life stages of different species of salmonids. Most of the freshwater stages are in rivers and streams. For lakes, Oliver and Fidler (2001) note that the continued application of the +/- 1ºC change from the natural conditions is expected to protect aquatic life in natural lake environments.

The temperature profiles for the four stations in Shawnigan Lake on March 9, 2020 and September 20, 2020 sampling are shown in Figure 2. Thermal stratification was present only for the September samples. Stratification was most pronounced at the North Basin (L1, 1199901) and South Basin (L2 E315291) sites with the thermocline – more correctly called the metalimnion (Wetzel, 2001) - occurring from about 7m – 18m and 7m – 12m respectively (Figure 2). (Note: The less pronounced thermocline at the more shallow West Arm (L3, 1199903) and North Beach (L4, 1199904) sites also started at about 7 m and extended to about 10 - 11m (Figure 2). The temperature in the epilimnion at all of the sites ranged from about 12ºC to 19.2ºC. On March 9, 2020, the temperature at all depths at all of the sites ranged from 5.0ºC - 5.9ºC. The temperature data are not dissimilar to those found by Javorski and Barlak (2020) for the March 2018 and 2019 and August 2018 samples at three of the same sites. Their L2 was in a different location (see Section 2.1 and Figure 1)

The temperatures in the epilimnion exceed the aesthetic water quality guideline of 15ºC, but drinking water intakes are generally in deeper water.

3.2 Dissolved Oxygen

Dissolved oxygen is necessary for aquatic life, but the concentration of dissolved oxygen also affects chemical reactions and low dissolved oxygen can lead to reducing conditions and the release of adsorbed metals as well as phosphorus. The concentration of dissolved oxygen in lake waters is dependant on temperature with decreasing concentrations at increasing temperatures. But the concentration of dissolved oxygen in lakes can be reduced during decomposition of organic matter present due to dying biota or input of suspended organic matter from streams or overland flow.

The water quality objective for dissolved oxygen in Shawnigan Lake is ≥ 5 mg/L at any depth of the water column throughout the year (Rieberger, 2007, Javorski & Barlak, 2020). In September, the dissolved oxygen was <5 mg/L below 8m at sites L2 South Basin and L3 West Arm and it decreased with depth at site L4 North Beach and to a lesser extend at site L1 North Basin (Figure 3). Chlorophyll *a* which is a measure of phytoplankton decreased between March and September (see Section 3.6) and the reduced dissolved oxygen concentrations in September may be due to the oxygen used to decompose the fall die-off of the phytoplankton. In addition, site L2 (South Basin) receives the sediment load from South Shawnigan Creek and L3 (West Arm) receives input from the creek entering the West Arm. Both inputs will likely contain organic

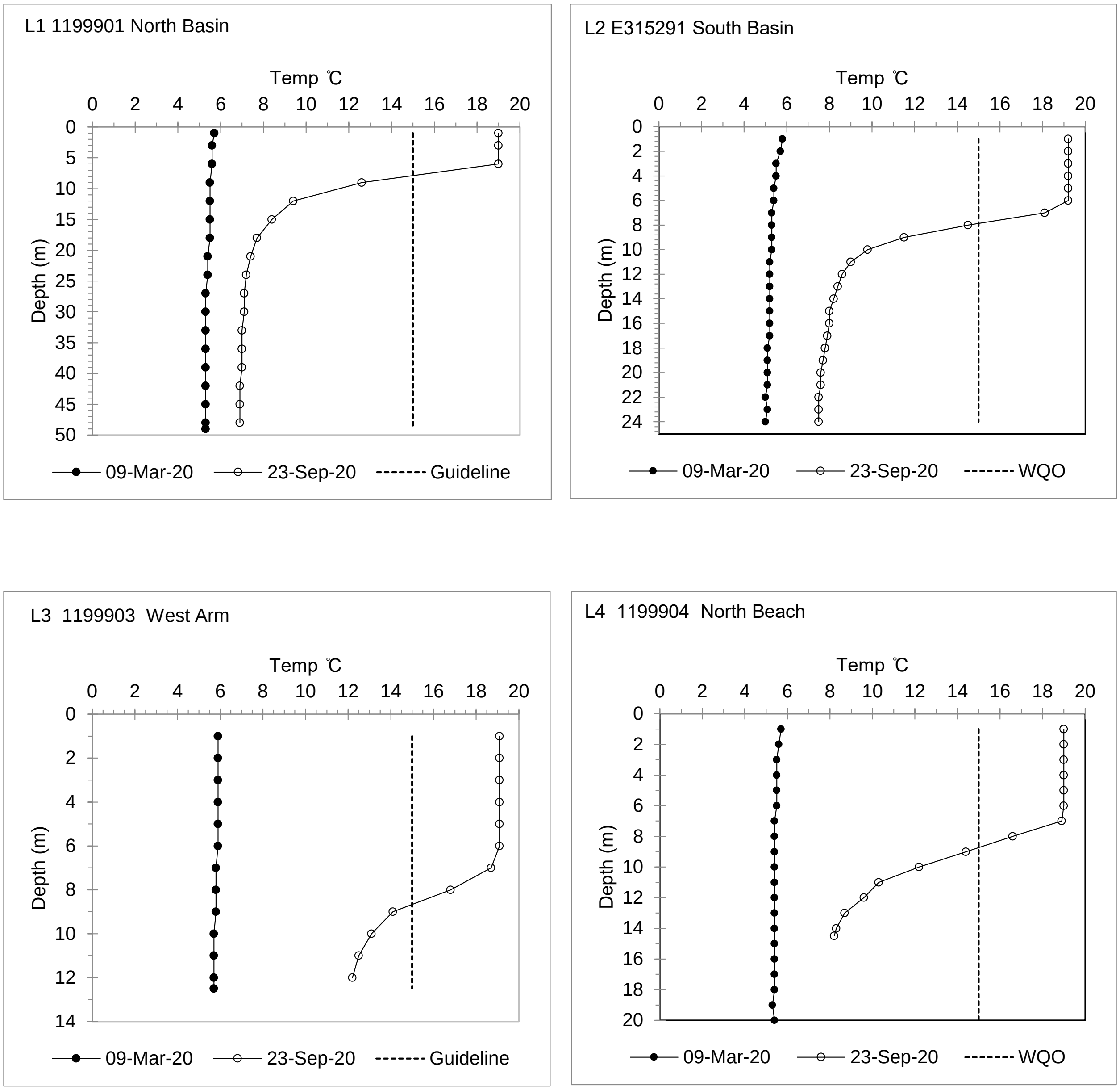
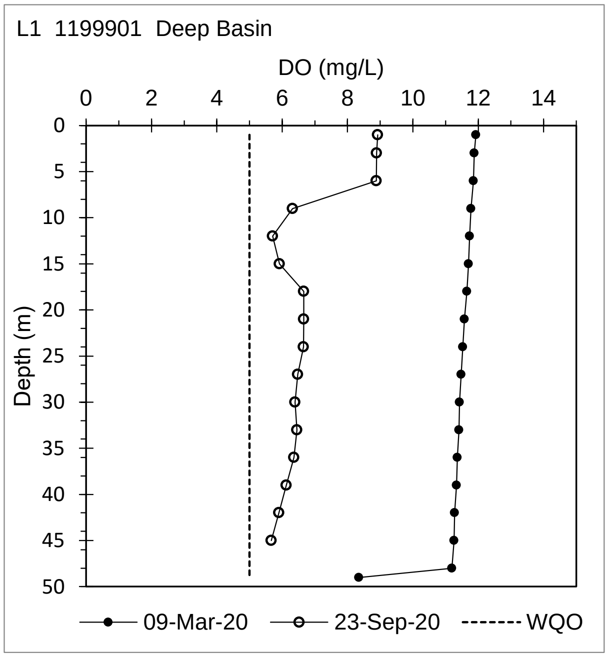
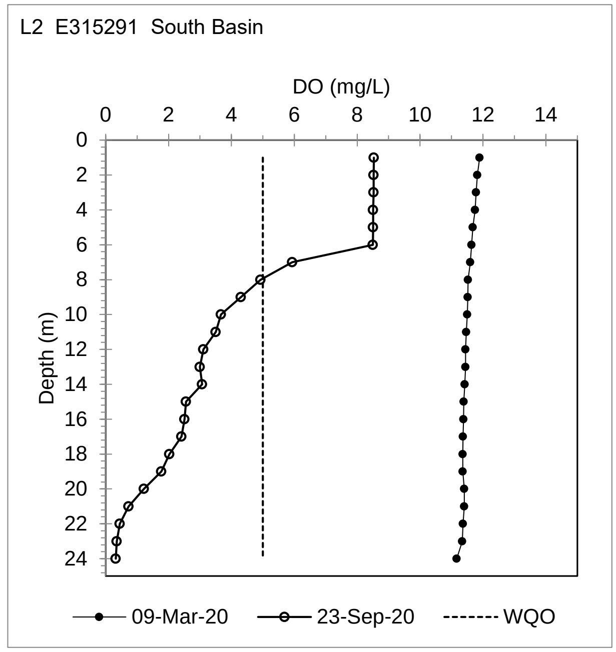
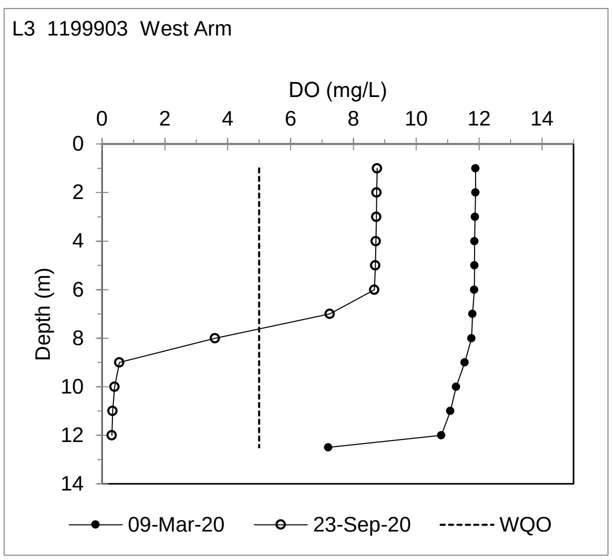


Figure 2. Depth (m) vs temperature (^{O}C) for the four basin sites on Shawnigan Lake. WQO is the MOE water quality objective for Shawnigan Lake.







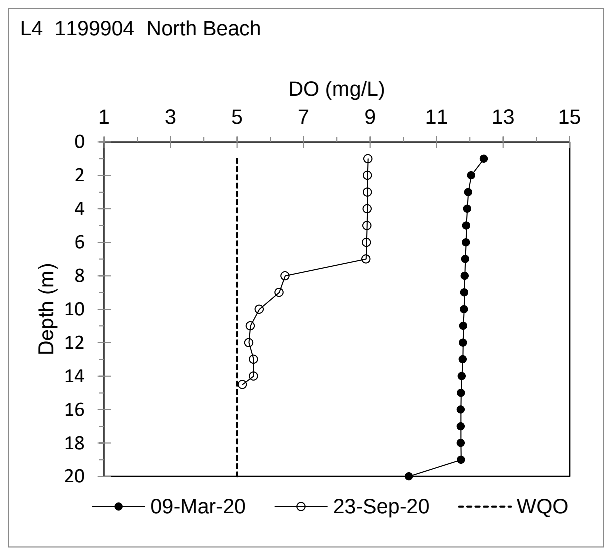
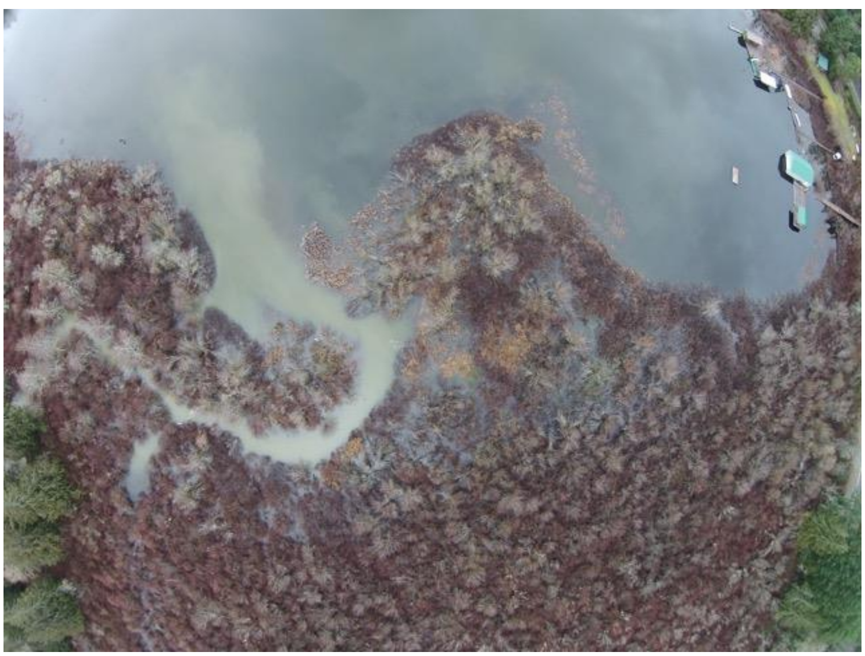


Figure 3. Depth (m) vs dissolved oxygen (mg/L) for the four Shawnigan Lake Basin stations. WQO is the minimum MOE water quality objective for Shawnigan Lake.

material which when decomposed will reduce oxygen levels. The levels of suspended solids were less than the detectable limit (<3 mg/L) at both L2 (Appendix III-B) and L3 (Appendix III-C) in March and September, but a large sediment plumes (e.g., January 17,2016, Photograph 1) have been observed from South Shawnigan Creek after most heavy rains in the past decade (Dave Hutchison, pers. com.) and the material would have settled to the bottom of this first large basin at the south end (L2 South Basin) by the time the samples were collected. A third contribution to the reduced oxygen levels is the presence and subsequent death and decomposition of dense mats of Eurasian watermilfoil. The plant is found in shallow waters (up to 10 m). However, Eurasian watermilfoil propagates sexually as well asexually by fragmentation. Fragmentation occurs due to mechanical disruption – motorized boats and poor removal procedures – and naturally during the summer. The fragments could move via wind and currents to the deeper waters, fall to the bottom, and increase the organic content of these waters. No data are available on the organic enrichment of the these deeper waters.

The low dissolved oxygen concentrations would limit suitable habitat for many fish and other aquatic organisms, but the depths where oxygen concentrations were > +/- 5 mg/L had warm > 12^{o}C temperatures possibly at stress levels. No data are available for the summer months when the surface water would be warmer and when the dissolved oxygen concentration is not known.



Photograph #1. The sediment plume from South Shawnigan Creek into the south end of Shawnigan Lake, January 17, 2016. Photo by Russell Robertson.

3.3 pH

The following is paraphrased from McKean and Nagpal (1991) which is a literature summary prepared as background for developing the British Columbia Water Quality Guidelines for pH.

pH is a measure of the hydrogen ion activity (aH^+) and is given by the logarithmic equation $pH = - \log_{10}aH^+$. Values range from 0 to 14 with pH 7 neutral and pH values <7 acidic and >7 basic.

In general, the pH of surface waters depends on the amount of precipitation and the rate of weathering in bedrock and soils – with subsequent leaching or overland flow to surface waters. In addition, oxidation of sulphur and nitrogen to sulphuric acid and nitric acid from natural and anthropogenic sources results in acid rain. On Vancouver Island part of the Insular Tectonic Region, the general range in surface water pH is 6.6 – 7.8.

The pH for drinking water supplies is based on pH dependency of different reactions: the solubility of salts and metals, including phosphorus; the corrosion of metal and asbestos-cement pipes; the precipitation of carbonate salts; and decreased effectiveness of chlorination and formation of trihalomethanes (Health and Welfare Canada, 1989, from McKean and Nagpal, 1991; Moore, 1998). The BC Ministry of Health Guidelines are adopted from the Guidelines for Drinking Water Quality (1989). They are pH from 6.5 – 8.5 for raw drinking water requiring on disinfection. These values are also used by CCREM (1987, from McKean and Nagpal, 1991).

McKean and Nagpal (1991) included an extensive summary of the literature on the different effects of pH on aquatic organisms. For most aquatic systems, the pH criteria for the protection of aquatic life are 6.5 – 9.0. Changes in pH can occur within this range, but not if the change affects carbon dioxide concentrations (McKean and Nagpal, 1991) due in part to increased decomposition processes (see below).

The pH levels with depth at the four Shawnigan Lake sites on March 9, 2020 and September 23, 2020 are given in Figure 4. In September, pH decreased in the hypolimnion, particularly at site L1 (North Basin,1199901) and L2 (South Basin, E315291) where the levels were below the guideline of pH 6.5. In March, the values were reasonably constant with depth, but less than the guideline at the West Arm site (L3, 1199903). There is not one easy explanation for this decrease. Javorski and Barlak (2020) suggest that it is due to increased concentration of carbon dioxide due to decomposition processes, but the carbonic acid produced can then lose protons producing alkaline bicarbonate and carbonate. What is important is that all values were greater than pH = 6.0, and values between pH 6.0 and 6.5 are unlikely to harm fish unless free carbon dioxide is >100 mg/L (McKean and Nagpal, 1989). No data are available for carbon dioxide. The only suggestion that this may be occurring is that the dissolved oxygen levels showed the same *general* trend - decreasing with depth - as with pH.

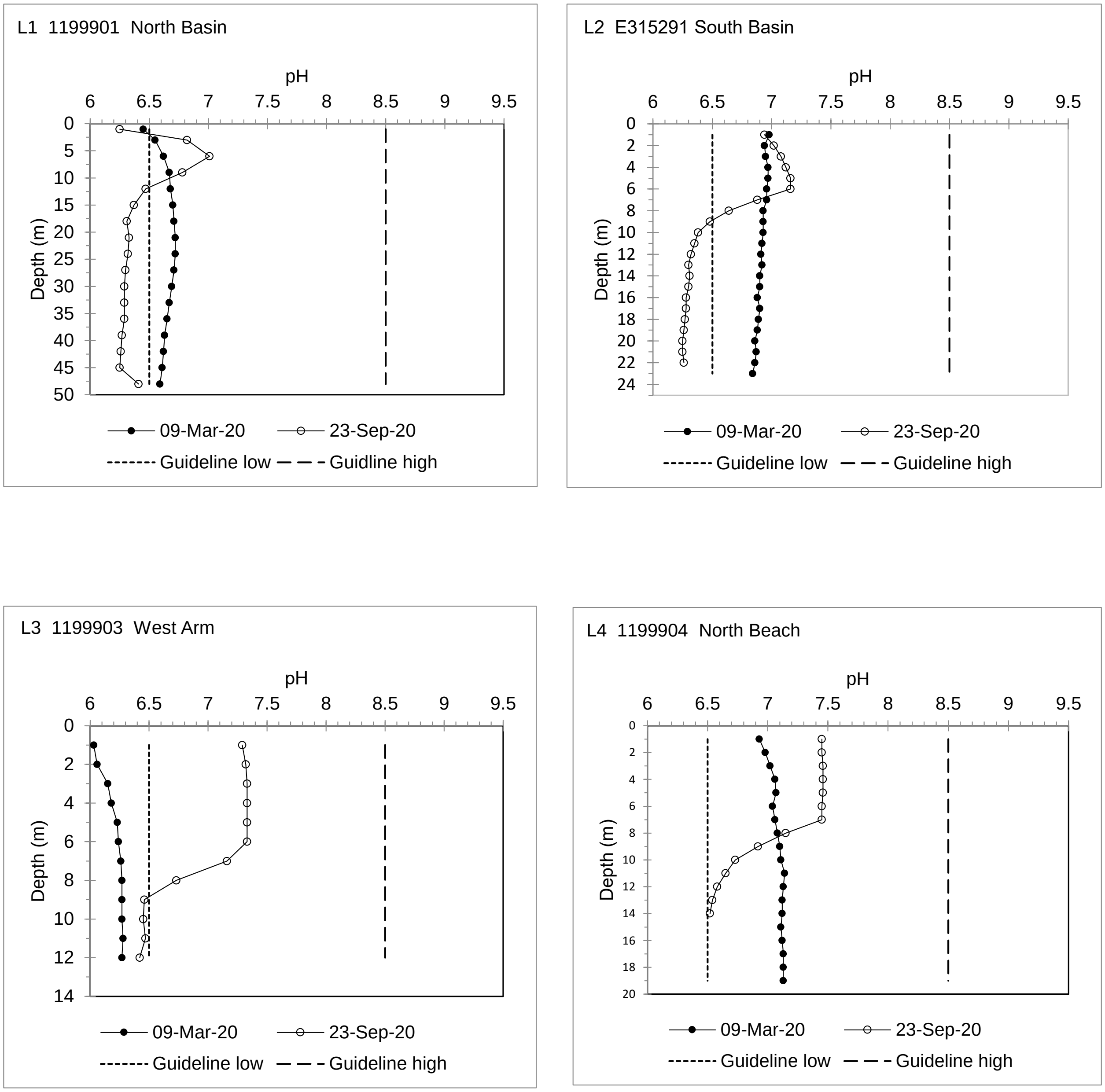


Figure 4. Depth (m) vs pH for the four basin stations on Shawnigan Lake on March 9, 2020 and September 23, 2020. The low (pH = 6.5) and high (pH= 9.0) Guidelines are the provincial guidelines for the protection of aquatic life.

3.4 Water Clarity

Water clarity or transparency in lakes allows light penetration for phytoplankton and algae growth, but is also an indicator of water quality because it decreases with increasing colour (frequently due to increased dissolved organic matter), algal (including phytoplankton) abundance, and suspended material (Rieberger, 2007). The suspended material includes soil particles such as clay, silts and organic matter and microorganisms. They make the water aesthetically displeasing, provide habitat for bacteria and can interfere with disinfection of drinking water (BC Ministry Environment, Lands and Parks, 1997).

Clarity is measured in two ways: turbidity which is a measure of light scattering and reported in Nephelometric Turbidity Units (NTU); and Secchi depth reported as the depth to which the distinction between black and white on a 20 cm diameter disk is apparent. Davies-Colley and Smith (2007) found that Secchi depth is better than turbidity in assessing suspended sediment and suggested that it should supplant nephelometric turbidity. Both are included in the Shawnigan Lake water quality objectives.

3.4.1 Turbidity

The turbidity results for the Shawnigan Lake sites are given in Figure 5. The water quality objective is a mean monthly level of ≤ 1 NTU with no one value greater than 5 NTU. As samples were collected only on one day in each of two months, mean monthly values cannot be calculated. However, all the measurements on March 9, 2020 were less that the objective. In September, the turbidity at 15 m (L2, E315291) and 9 m (L3 1199903) exceeded 1 NTU, but were less than 5 NTU. Javorski and Barlak (2020) were also not able to determine monthly means, but indicated that the individual values were in general < 1 NTU.

The turbidity objective is for samples collected within 10 m of domestic intakes. Only sites L3 1199903 (West Arm) and L4 1199904 (North Beach) reflect conditions near domestic inlets (Javorski and Barlak, 2020) and only L3 West Arm had values > 1 NTU close to the bottom in September.

3.4.2. Secchi Depth

Rieberger (2007) notes that care should be taken in measuring Secchi depths as various factors (e.g., phytoplankton distribution, zooplankton grazing and weather conditions) can affect the readings. The Secchi depths on March 9, 2020 and September 23, 2020 at the four sites on Shawnigan Lake are give in Figure 6. The objective (≥ 5m) was not attained at any of the sites in March. However, the objective is supposed to be an annual mean and thus sufficient data are not available to determine an annual mean. But the decreased depths in March 2020 may be in part due to increased phytoplankton as measured by chlorophyll *a* concentrations, which were at or greater than the water quality objective of ≤ 2 µg/L (see Section 5). In 2018, the objective in the West Arm with three samples over the year did not meet the objective of an annual mean (Javorski and Barlak, 2020).

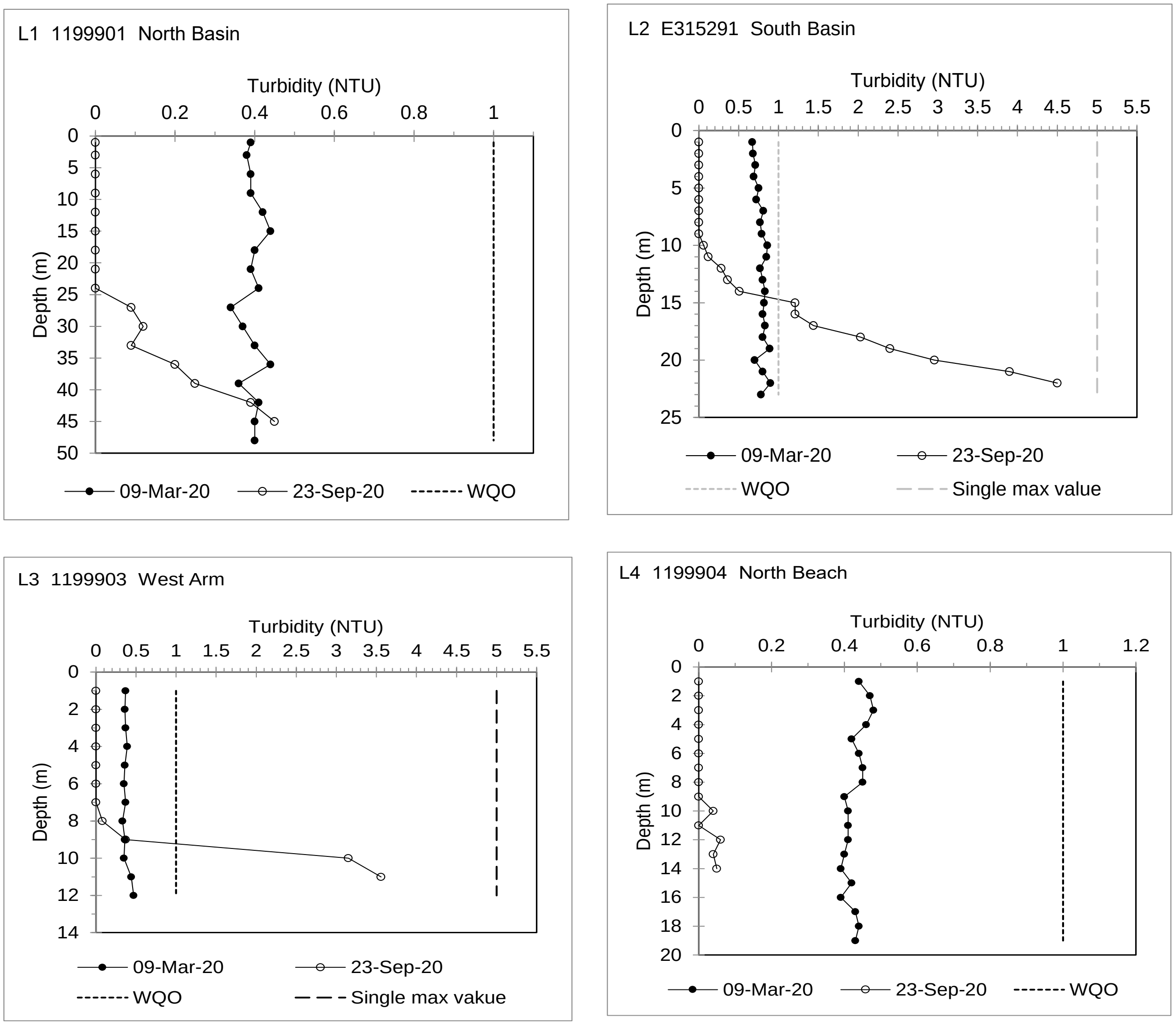


Figure 5. Depth (m) vs turbidity (NTU) for the four basin stations on Shawnigan Lake March 9, 2020 and September 23, 2020. WQO is the MOE water quality objective for Shawnigan Lake which is mean monthly value ≤ 1NTU. In addition, no individual sample can exceed 5 NTU, the single maximum value.

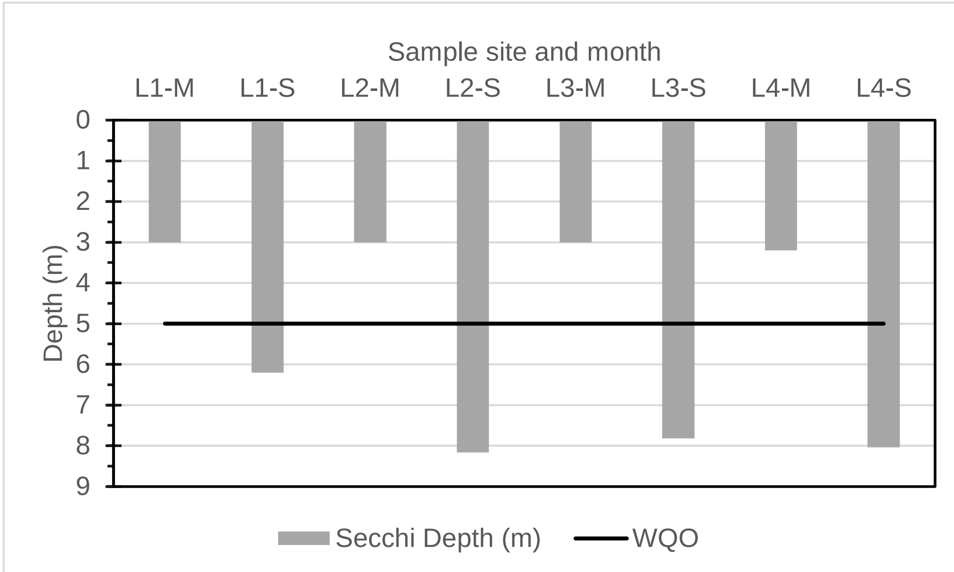


Figure 6. Secchi Disk depths at the four basin stations in Shawnigan Lake (L1 = North Basin, L2 = South Basin, L3 = West Arm Basin, L$ =- North Beach) on M = March 9, 2020 and S = September 23, 2020. WQO is the MOE water quality objective for Shawnigan Lake.

3.5. Nutrients

Nitrogen, phosphorus and total organic carbon are the main nutrients studied in freshwater aquatic systems (e.g., Wetzel, 2001). In addition, the ratio of total nitrogen (TN) to total phosphorus (TP) is another useful index of trophic status in lakes and nutrient limitation (Rieberger, 2007).

3.5.1 Nitrogen

There are organic and inorganic forms of reactive nitrogen compounds that move via lightning and biological and chemical processes among the atmosphere and the terrestrial and aquatic ecosystems (Galloway et al., 2003). Human development (e.g., septic wastes, artificial fertilizers, manure, cultivation of nitrogen fixing legumes, combustion of fossil fuels) disrupts the natural cycle resulting in the accumulation of different forms of nitrogen in different components of the cycle. One important component being freshwater lakes. In lakes, nitrogen is a required nutrient for phytoplankton, periphyton and macrophytes.

The Water Quality Objective (WQO) for total nitrogen is ≤ 250 µg/L. This is a mean of two samples (top and bottom) for sites L3 West Arm (1199903) and L4 North Beach (1199904) of three samples (top, middle and bottom) for sites L1 North Basin (1199901) and L2 South Basin (E315291) collected during spring turnover when the lake is well mixed (Javorski and Barlak, 2020). The concentration of organic nitrogen and total nitrogen at the four sites in Shawnigan Lake are shown in Figure 7A. The mean of two depths for each site on March 10, 2020 and September 22, 2020 are given in Table 2. The March sample represents the time when the lake is well mixed. (Note that there is only a top and bottom sample for L1 and L2.) The mean concentration of total nitrogen exceeded the WQO for Shawnigan Lake in the March sample in the West Arm (L3, 1199903) (Table 2). This was due to the high total nitrogen at the bottom site where the concentration of organic nitrogen is shown as greater than the total nitrogen (Figure N-A), probably due to the high organic nitrogen and margin of error in the analyses. Javorski and Barlak (2020) found exceedances at both the North Basin and the West Arm sites in March 2018 and 2019.

Table 2. Mean concentration of total nitrogen at the four stations on Shawnigan lake for the samples collected March 20, 2020 and September 25, 2020. The water quality objective is ≤ 250 µg/L for at least three samples (top, mid depth and one meter above the bottom) for L1 and L2 and two samples (top and one meter above the bottom) for L3 and L4.

Station	Mean Conc (µg/L), n=2	
	10-Mar-20	25-Sep-20
L1, 1199901 (North Basin)	237	209
L2, E315291 (South Basin)	215	225
L3, 1199903 (West Arm)	253	203
L4, 1199904 (North Beach)	233	162

3.5.2 Phosphorus

Phosphorus moves between terrestrial and aquatic systems via chemical and biological processes. The gaseous component is negligible. Phosphorous is required for metabolic process in plants and animals and in fresh water it is usually the least abundant nutrient and is referred to as the limiting nutrient (e.g., Wetzel, 2001). Sources of phosphorus include fertilizers, manure, and septic wastes (Robertson et al.,1998; Sharpley and Moyer, 2000; Turner and Haygrarth, 2000) which can move to adjacent surface waters via subsurface flow and groundwater (Holman et al., 2008) or erosion. Most, but not all detergents are phosphate free since the need to reduce phosphorus fresh waters was recognized (Vallentyne, 1974, Schindler and Vallentyne, 2008). The phosphorus is largely adsorbed in soil (Holman et al., 2000, USGS, 2013), suspended sediment and the lake sediment. Factors that limit phosphorus adsorption and thus make it available in the soil solution or lake water are low oxygen concentrations, high pH (>7), and lack of available surface area on mineral oxides and clay particles (Domagalski and Johnson, 2012).

In Shawnigan Lake water samples only dissolved and available phosphorus (called orthophosphate) and total phosphorus were measured (Appendices III-A, III-B, III-C, and III-D). Orthophosphate exists as $H_2PO_4^{2-}$ in water of pH = 6 - 8 as is present in Shawnigan Lake. Total phosphorus concentrations in the top and bottom samples from the four stations in both March and September are shown in Figure 7-B as is the maximum water quality objective of ≤ 8 µg/L. However, the objective is at spring turnover so only applies to the March samples. But the bottom samples collected at sites L2 South Basin (E315291) and L3 West Arm (1199903) on September 25, 2020 exceeded the objective (9.9 µg/L and 9.6 µg/L, respectively). At sites L2 South Basin (E315291) and L3 West Arm (11199903) the dissolved oxygen concentrations were below the objective of 5 mg/L below 8 m and fell to <1 mg/L in the bottom four meters (Figure 7-B). Low dissolved oxygen is one factor that limits phosphorus adsorption (Domagalski and Johnson, 2012) and in lakes the release of adsorbed phosphorus is called internal loading (Wetzel, 2001). Javorski and Barlak (2020) also found high total phosphorus in the hypolimnion when the when the water in the West Arm (L3) was stratified. Presumably, this is not a concern as the lake flushes during the winter months (Nordin and McKean,1984), but it would be useful to have phosphorus data from the summer months.

3.5.3 Nitrogen to Phosphorus Ratio (N:P)

Although most freshwater systems in the temperate area are phosphorus limited (e.g., Schindler and Vallentyne, 2008), algae require nitrogen and phosphorus in particular ratios and knowing these ratios and what is available in the lake waters is can be used to assess changes in phytoplankton communities (Nordin,1985; Rieberger, 2007). In addition, the N:P ratio can provide information about nutrient limitation (Rieberger, 2007). In general, N:P ratios < 20:1 are nitrogen limited and those > 20:1 are phosphorus limited (Javorski and Barlak, 2020).

The water quality objective for N:P ratios is 30:1 calculated using average total nitrogen and phosphorus concentrations. The N:P ratios for the samples collected from the top and bottom at each of the four stations on Shawnigan Lake as well as the water quality objective are shown in Figure 7-C. There is only one sample for each ratio given in Figure 7-C, but it is worth considering these limited results. All of the values are > 20 confirming that Shawnigan Lake is phosphorus limited. Three of the values of the bottom samples at sites L2 (South Basin), L3 (West Arm) and L4 (North Beach) are less than the minimum objective in the September samples. These three samples had the highest total phosphorus concentrations (L2 = 9.9 µg/L, L3 = 9.6 µg/L and L4 = 5.6 µg/L, Appendices III-B,III-C and III-D) which would reduce the ratio. Javorski and Barlak (2020) found the ratios in 2018 and 2019 were all above the objective, but they had more data.

3.5.4 Total Organic Carbon

Carbon is the main component of plants and animals. It enters the atmosphere as carbon dioxide, is converted to sugars in plants during photosynthesis, is incorporated into numerous materials in animals during ingestion and digestion and is released during defecation and decomposition when the plants and animals die. This is a simplification, but emphasizes the importance of carbon in ecosystems. This occurs in terrestrial and aquatic systems. Carbon input to lakes is from both allochthonous (outside plants and soils) and autochthonous (inside algae and aquatic plants) sources (Wetzel, 2001).

There is a total organic carbon objective not because of toxicity of the acids, but because certain organic acids, particularly humic and fulvic, react with chlorine during water chlorination to produce disinfection by-products (DBPs) including trihalomethanes (THM) which are a health hazard (Moore, 1998). It involves a series of reactions which are pH dependent (Moore, 1998). Increased TOC can also give the water aesthetically displeasing colour.

The concentrations of total organic carbon (TOC) and dissolved organic carbon (DOC) in the top and bottom samples at the four stations in Shawnigan Lake, and the maximum water quality objective are shown in Figure 7-D. The objective for TOC is ≤ 4 mg/L. There is no objective for DOC, but as is apparent in Figure 7-D, most of the total organic carbon is dissolved. The TOC exceeded the objective in the top sample in March (4.02 mg/L) and the bottom sample in September (4.29 mg/L) at station L3 in the West Arm (Figure 7-D). Javorski and Barlak (2020) found one minor exceedance of 4.34 mg/L in the West Arm in 2018. All of the concentrations of TOC are greater than 3.53 mg/L (Appendices III-A, III-B, III-C and III-D) suggesting decomposition of organic material in the whole water column of the lake.

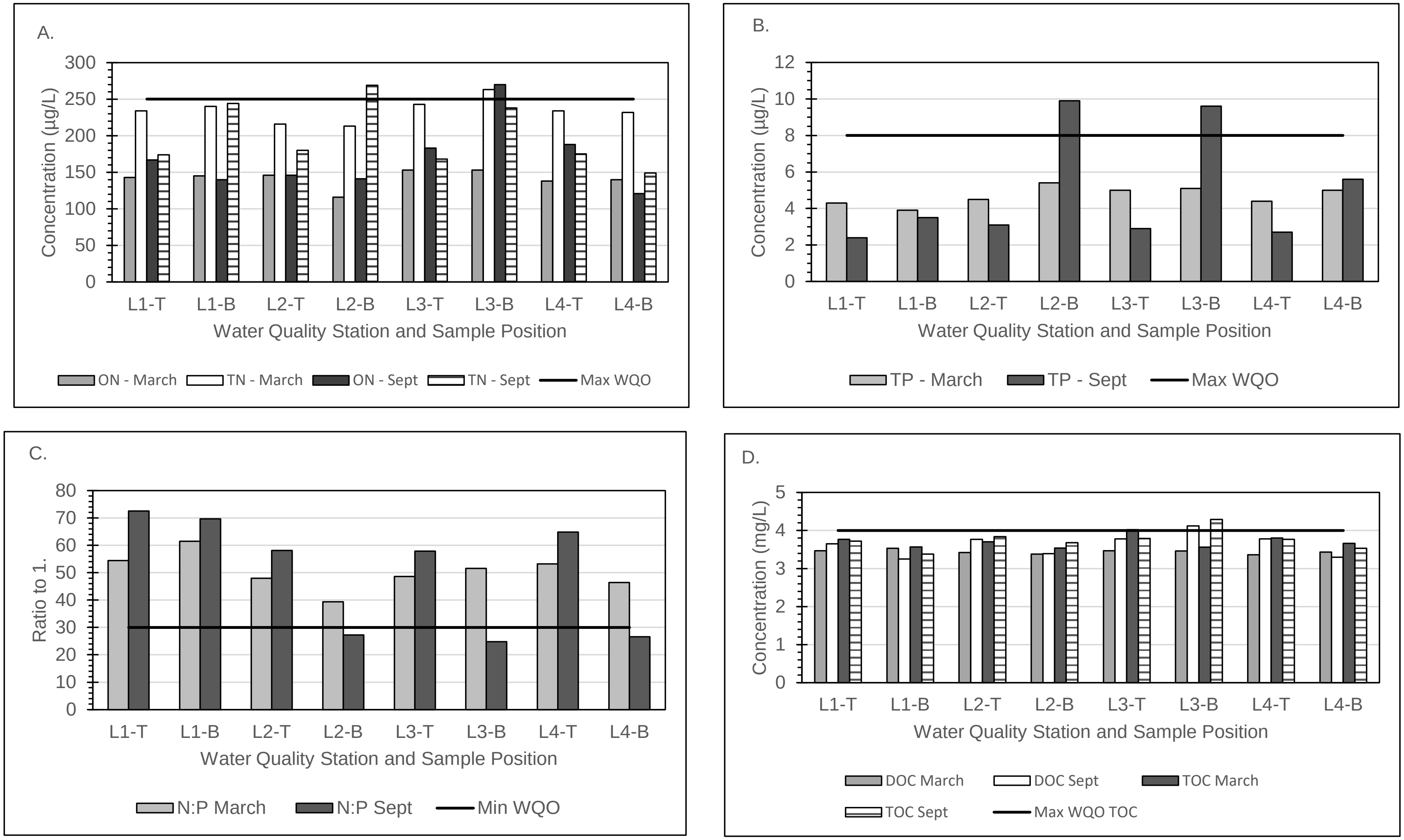


Figure 7. **A**. Total organic nitrogen (ON), total nitrogen (TN), **B**. total phosphorous (TP), **C**. N:P ratio, **D**. total dissolved organic carbon (DOC), total organic carbon (TOC) and the associated maximum (Max) or minimum (Min) water quality objectives (WQO) on March 10, 2020 and September 25, 2020. L1 is the North Basin (1199901), L2 is the South Basin (E315291), L3 is the West Arm (1199903) and L4 is the North Beach (1199904). T is the sample at 1 m and B is the bottom sample (2 m from bottom).

3.6. Chlorophyll *a*

Chlorophyll *a* is a photosynthetic pigment in green plants; in the water column, it is found in algae, including phytoplankton and cyanobacteria (blue-green algae). In limnological studies, the concentration of chlorophyll *a* is a straightforward measure of phytoplankton biomass (Nordin and McKean, 1984) and thus lake productivity. Low productivity lakes are referred to as oligotrophic and high productivity lakes as eutrophic. High productivity is due largely to phytoplankton and can decrease water clarity, increase taste and odour problems, decrease hypolimnion dissolved oxygen due to use of water during their decomposition and increase the possibility of the presence of certain toxins produced by cyanobacteria (Rieberger, 2007).

The chlorophyll *a* concentrations at the four lake stations in March and September as well as the maximum water quality objective are shown in Figure 8. The water quality objective for chlorophyll a is ≤ 2 µg/L in epilimnetic waters in the main basin, sampled during the growing season, May through August (Javoroski and Barllak, 2020). Samples for this report were only in March and September and higher values may be present during the growing season. All of the March samples exceeded the objective with values ranging from 2.01 µg/L to 3.12 µg/L, although L3 (West Arm) and L4 (North Beach are not in the main basin. Javorski and Barlak (2020) found no exceedances in the north and south basins in 2018, but some in 2008 and 2013 (data summarized in Javorski and Barlak, 2020). Klaff (2002) from Rieberger (2007) suggested an upper threshold of 3 µg/L for oligotrophic lakes, suggesting the West Arm may be on the upper edge of oligotrophy.

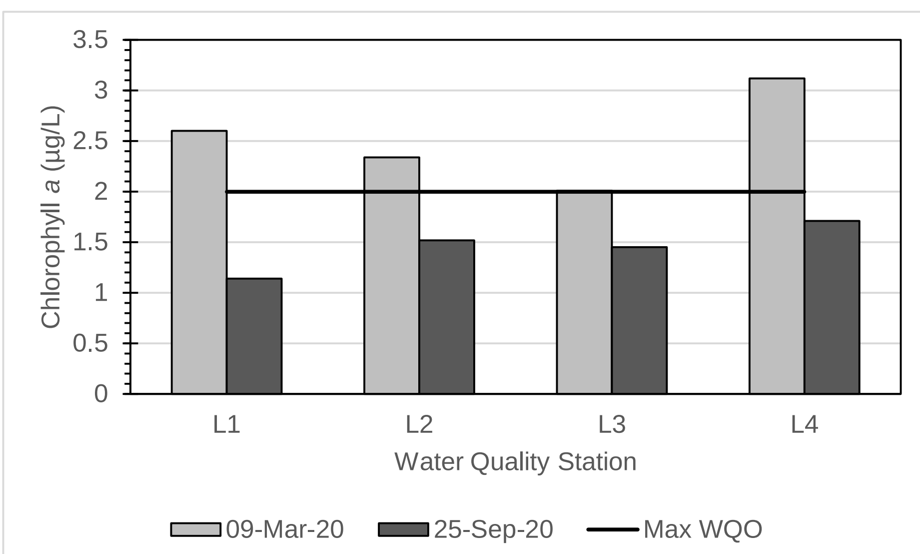


Figure 8. Chlorophyll *a* concentration (µg/L) at the four stations in Shawnigan Lake on 09-Mar-20 and 25-Sep-20. L1 = North Basin (01199901), L2 = South Basin (E315291), L3 = West Arm (1199903), and L4 = North Beach (1199904). Max WQO is the MOE maximum water quality objective for chlorophyll *a.*

4.Total and Dissolved Metals

The results of the concentrations of all of the total and dissolved metals analysed are in Appendices III-A, III-B, III-C, and III-D and many are below the detectable limit. Table 3 is a summary of the minimum and maximum concentration at each of the four lake stations for the metals that were present in detectable limits. Also in Table 3 are available water quality guidelines with the shaded boxes for those that exceeded one of the four BC water quality guidelines (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-guidelines/approved-wqgs/drinking-water-and-recreation/source_drinking_water_quality_guidelines_bcenv.pdf). Note that many of the metals do not have guideline levels.

There are eight exceedances: five for manganese, and three for iron. There are two guidelines for total manganese: 0.012 mg/L is the maximum acceptable concentration (MAC) for drinking water; and 0.02 mg/L is the drinking water aesthetic concentration. All of the maximum values (Table 3) are at the bottom in September and were the only positions where the MAC for drinking water was exceeded at L1 (North Basin), L2 (South Basin) and L3 (North Beach) (Appendices III-A, III-B, and III-C). The further exceedance of the drinking water aesthetic concentration for total manganese (L4, North Beach, Table 3) was only at the bottom in September (Appendix III-D). Total iron exceeded the guideline for the protection aquatic life - maximum concentration - in the bottom sample from station L3 (West Arm) only in September and dissolved iron exceeded the same guideline in the same sample (Table 3, Appendix III-C). Dissolved iron also exceeded the same guideline in the bottom sample at station L2 (South Basin) in September (Table 3, Appendix III-B). The high total iron concentrations may be due to the suspended material entering the West Arm and South Basin.

Table 3. Minimum and maximum concentrations of the metals for the four water quality stations on Shawnigan Lake with levels above the detection limit. See Appendices 1-4. BC water quality guidelines are included when available. a = drinking water max, b = aquatic life max, c = aquatic life 30-day, d = drinking water aesthetics. * is the detection limit. Shaded boxes exceed the guideline.

Parameter	Guideline	Units	Water Quality Station							
			L1 (1199901) North Basin		L2 (E315291) South Basin		L3 (1199903) West Arm		L4 (1199904) North Beach	
			min	max	min	max	min	max	min	max
Aluminum - T		mg/L	0.0085	0.052	0.0078	0.0884	0.0068	0.0432	0.0080	0.0468
Al – dis	0.2[a]	mg/L	0.0052	0.0276	0.0052	0.0541	0.0041	0.0282	0.0050	0.0261
Arsenic – T	0.025[a] 0.005[b]	mg/L	0.00012	0.00018	0.00011	0.00020	0.00012	0.00034	0.00010	0.00018
As – dis		mg/L	0.00012	0.00019	<0.00010*	0.00020	0.00012	0.00033	0.00011	0.00018
Barium – T	1.0[c]	mg/L	0.00479	0.00547	0.00392	0.00680	0.00540	0.00984	0.00488	0.00558
Ba – dis		mg/L	0.00475	0.00612	0.00359	0.00661	0.00535	0.00758	0.00459	0.00539
Calcium – T		mg/L	6.39	7.26	5.31	7.23	7.37	9.22	6.27	7.32
Ca – dis		mg/L	6.18	7.39	5.36	7.41	7.52	9.08	6.19	7.27
Chromium – T		mg/L	<0.00010*	0.00014	<0.00010*	0.00034	<0.00010*	0.00014	<0.00010*	0.00014
Cr – dis		mg/L	<0.00010*	0.00014	<0.00010*	0.00014	<0.00010*	0.00011	<0.00010*	0.00014
Copper – T	0.5[a]	mg/L	0.00069	0.00118	0.00067	0.00085	0.00070	0.00076	0.00067	0.00537
Cu – dis		mg/L	0.00061	0.00092	0.00060	0.00064	0.00038	0.00066	0.00057	0.00064
Iron – T	1.0[b]	mg/L	0.026	0.075	0.030	0.747	0.035	1.95	0.031	0.040
Fe – dis	0.35[b]	mg/L	0.010	0.030	0.014	0.481	0.019	1.46	<0.010*	0.015
Magnesium – T		mg/L	1.20	1.38	1.15	1.41	1.32	1.42	1.21	1.39
Mg – dis		mg/L	1.14	1.36	1.10	1.32	1.32	1.40	1.20	1.32
Manganese – T	0.02[d] 0.12[a]	mg/L	0.00257	0.172	0.00340	0.188	0.00311	0.477	0.00270	0.0660
Mn - dis		mg/L	0.00023	0.151	0.00068	0.184	0.00041	0.486	0.00025	0.0364

Table 3 continued on next page

Table 3 continued

Parameter	Guideline[1]	Units	Water Quality Station							
			L1 (1199901) North Basin		L2 (E315291) South Basin		L3 (1199903) West Arm		L4 (1199904) North Beach	
			min	max	min	max	min	max	min	max
Molybdenum – T	0.088[a]	mg/L	0.000068	0.000095	0.000058	0.000077	0.000060	0.000098	0.000060	0.000117
Mo – dis		mg/L	0.000066	0.000080	<0.000050*	0.000081	0.000052	0.000077	0.000057	0.000066
Potassium – T		mg/L	0.265	0.270	0.250	0.299	0.280	0.346	0.286	0.303
K -dis		mg/L	0.273	0.324	0.254	0.321	0.300	0.360	0.291	0.325
Rubidium – T		mg/L	0.00027	0.00028	0.00029	0.00032	0.00024	0.00038	0.00025	0.00029
Rb – dis		mg/L	0.00026	0.00029	0.00022	0.00036	0.00023	0.00038	0.00024	0.00028
Silicon – T		mg/L	1.77	2.98	1.80	3.01	1.74	2.96	1.75	2.61
Si – dis		mg/L	1.78	2.86	1.75	2.94	1.76	2.90	1.70	2.56
Sodium – T		mg/L	3.10	3.58	3.07	3.67	3.30	3.64	3.14	3.62
Na – dis		mg/L	3.24	3.51	3.16	3.58	3.23	3.54	3.16	3.44
Strontium – T		mg/L	0.0235	0.0297	0.0220	0.0340	0.0272	0.0355	0.0244	0.0302
Sr – dis		mg/L	0.0251	0.0300	0.0228	0.0338	0.0278	0.0332	0.0248	0.0294
Sulfur – T		mg/L	0.50	0.90	0.69	0.94	0.52	0.84	0.78	0.90
S – dis		mg/L	0.70	0.95	0.78	0.87	0.77	0.81	0.76	0.97
Titanium – T		mg/L	<0.00030*	0.00095	<0.00030*	0.00226	<0.00030*	0.00267	<0.00030*	0.00267
Ti – dis		mg/L	<0.00030*	<0.00030*	<0.00030*	0.00093	<0.00030*	0.00030	<0.00030*	0.00095
Zinc – T		mg/L	<0.0030*	<0.0030*	<0.0030*	<0.0030*	<0.0030*	<0.0030*	<0.0030*	<0.0030*
Zn - dis		mg/L	<0.0030*	0.0027	<0.0030*	0.0025	<0.0030*	0.0019	<0.0030*	0.0025

5. Summary and Conclusions

Numerous samples collected in 2020 exceeded the water quality objectives for Shawnigan Lake, particularly in the September samples in the South Basin and the West Arm (Table 4). However, this must be qualified as samples were collected on only two dates and except the depth profiles, from only the top and bottom (Table 5). As it is unlikely that more frequent samples will be collected in future years, it may be worthwhile reconsidering the criteria for the objectives. (See Recommendations)

Several results warrant mention. There were extremely low oxygen levels in the hypolimnion in the South Basin and West Arm in September (Figure 3). Javorski and Barlak (2020) also found low oxygen close to the bottom in their South Basin site (further away from the South Shawnigan Creek input, Figure 1) and the West Arm in August 2018. Adsorbed metals as well as phosphorus are released in anoxic conditions and total phosphorus exceeded the objective in the bottom samples at these two stations (Figure 7-B). At the same locations, total (and dissolved) iron exceeded the water quality guideline for aquatic life (Table 3) suggesting that the oxygen concentrations at these locations should be sampled more frequently. The increase in phosphorus can have an escalating effect as it can increase productivity which when the organisms die will further decrease the oxygen and potential for more phosphorus release. And this process can be accelerated as more organic sediment enters the lake and *M. Spicatum* dies and decomposes.

In September, the pH in the North Basin (L1, 1199901), the South Basin (L2, E315291) and the West Arm (L3, 1199903) were less that the lower guideline for pH in the hypolimnion and all of the pH values in March in the West Arm were less than the lower guideline (Figure 4). All of the values were greater than pH = 6 suggesting no harm to fish if there are low levels of carbon dioxide (see Section 3.3). However, several reactions such as the corrosion of metal and precipitation of carbonate salts and the decreased effectiveness of chlorination and formation of trihalomethanes are pH dependent suggesting indirect effects of pH less or greater than the guideline. The pH range of 6.5 – 8.5 should be included in the Water Quality Objectives for Shawnigan Lake

Neither Secchi depth (Figure 6) nor chlorophyll *a* (Figure 8) met the objective in March at the four sites (Table 4). The chlorophyll a is a measure of phytoplankton biomass and increased phytoplankton can reduce the Secchi depth (see Section 3.4.2). Chlorophyll *a* was 3.12 µg/L in March in the West Arm. The upper threshold for an oligotrophic lake is 3 µg/L suggesting that the West Arm may be at the upper threshold for an oligotrophic lake (see Section 3.6).

The total nitrogen concentrations in two samples (bottom in L2 South Arm in September and bottom in L3 West Arm in March) exceeded the objective of 250 µg/L as shown in Figure 7-A, but only the mean of the top and bottom samples in March in the West Arm exceeded the objective and it was only slightly greater (253 µg/L) than the objective.

Table 4. Summary of samples that did (Y) and did not (N) meet the Water Quality Objective for Shawnigan Lake. Because there were two sample dates, and only top and bottom samples except in depth profiles – no mid depth as required for L1 (North Basin) and L2 (South Basin) - the calculation of the objective was not possible for Secchi depth, total phosphorus, total nitrogen, and N:P ratio. Concentrations in the samples collected are compared to the objectives.

Parameter	Objective	L1 North Basin (1199901)		L2 South Basin (E315291)		L3 West Arm (1199903)		L4 North Beach (1199904)	
		Mar, 2020	Sep 2020	Mar, 2020	Sep 2020	Mar, 2020	Sep 2020	Mar, 2020	Sep 2020
Temperature[1]	15º C	Y	Y	Y	N (surface)	Y	N (surface)	Y	Y
DO	≥ 5 mg/L	Y	Y	Y	N (hypolim)	Y	N (hypolim)	Y	Y
Turbidity	≤ 1 NTU[2]	Y	Y	Y	N[a]	Y	N[a]	Y	Y
Secchi Depth	≥ 5 m	N	Y	N	Y	N	Y	N	Y
TN[3]	≤ 250 µg/L	Y	Y	Y	N[b]	N[b]	N[b]	Y	Y
TP[3]	≤ 8 µg/L	Y	Y	Y	N[b]	Y	N[b]	Y	Y
N:P3	≥ 30:1	Y	Y	Y	N[b]	Y	N[b]	Y	N[b]
TOC[3]	≤ 4 mg/L	Y	Y	Y	Y	N (4.02)	N (4.29)	Y	Y
Chlorophyll *a*	≤ 2 µg/L	N	Y	N	Y	N (2.01)	Y	N	Y

1 = There is no objective. The BC aesthetic guideline for drinking water was used.
2 = One max of 5 NTU.
3 = Only top and bottom samples
a = increased in hypolimnion, but < 5 NTU
b = bottom sample

The N:P ratios were less than the minimum objective (30:1) in the bottom samples at stations L2 (South Basin), L3 (West Arm) and L4 (North Beach), but greater than 20:1 suggesting that the waters were phosphorus limited.

The TOC exceeded the objective in the top sample in March (4.02 mg/L) and the bottom sample in September (4.29 mg/L) at station L3 in the West Arm (Figure 7-D). Most of the TOC was DOC (Figure 7-D) and thus if there are any plans to chlorinate the water, efforts to reduce the TOC should be considered (see Section 3.5.4).

Table 5. Summary of sample requirements for each of the parameters included in this report, whether the requirements were met, and comments.

Parameter	Sample Requirements (from Javoroski and Barlak, 2020)	Y = Satisfied in this report N = Not satisfied in the report	Comment
Temperature	No requirement Guideline anytime	Y	
Dissolved oxygen	Any depth throughout the year	Y	Profiles in March and September
Turbidity	Monthly mean for ≤ 1 NTU	N	Depth profile in each of two months
	Instantaneous for ≤ 5 NTU	Y	
Secchi Depth	Annual mean	N	Two sample times
Total Nitrogen (TN)	From three depths Average at spring overturn	N	One sample at two depths March which is in overturn
Total Phosphorus (TP)	From three depths Average at spring overturn	N	One sample at two depths March which is in overturn
N:P ratio	Calculated using average TN and TP	N	Calculated for each TN and TP
Total Organic Carbon	No requirement	Y	Compared to each data point
Chlorophyll *a*	Annual growing season average (May – August samples)	N	No samples in the growing period
Metals	No WQO Guidelines for individual samples	Y	

Recommendations

1. The samples for this report were collected in March and September, 2020. The sampling times for the WQO for Shawnigan Lake require more frequent sampling (e.g., to obtain monthly means, annual means, and samples during the growing period – May through August) and at three depths for different parameters (Table 1, Table 5). For this report, the WQO or guidelines were compared to individual data points. We recommend that a revised sampling schedule and some revisions of the WQOs should be implemented. These include one series of samples in June or July and samples from three depths in the north (L1) and south (L2) basins. It is unlikely that sufficient sampling will enable mean monthly values and whether this requirement is necessary should be discussed.

2. The input of suspended material to the West Arm and particularly to the South Basin and the relationship of land activities along South Shawnigan Creek to the sediment load to the creek should be carefully assessed and addressed.

3. The organic content of the sediments at all of the sample locations should be included in the sampling program. This would give an indication the possible contribution from Eurasian watermilfoil fragments to the deeper waters. In addition, studies on the best approach to control the Eurasian watermilfoil should be activated.

4. Data collected over the past 10-15 years should be examined for any trends, not just attainment. Visual changes using figures should be used. Various parameters do not meet the objectives and have not in previous reports as well (Javorski and Barlak, 2020). Plotting the data over time could help determine when and why changes occurred and if the concentration of parameters that are within the objectives are gradually changing. It would help identify any remedial measures that should be initiated.

5. The residents should be notified that the total manganese level sometimes exceeds both the maximum drinking water concentration and aesthetic drinking water level.
6. The microbiological indicators *Escherichia coli* (*E. coli*) should be incorporated into subsequent sampling studies. Although *Enterococci* are included in the Shawnigan Lake WQO, *Enterococci* are recommended as the indicator species in marine waters (Warrington et al., 2001).

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APPENDICES start on next page

Appendix I-A. March YSI ProDSS profile data for L1 North Basin

Lake Station: L1 North Basin		EMS ID: 1199901		Date: 09 - Mar - 20		Time: 10:30 – 11:00	
Parameter							
Depth (m)	Temp Cº	DO (mg/L)	DO % sat (calculated)	SC (µS/cm)	ORP	pH	Turbidity (NTU)
1	5.7	11.93	95.1	38.2	144	6.45	0.39
3	5.6	11.88	94.5	38.1	143	6.55	0.38
6	5.6	11.85	94.3	38.0	141	6.62	0.39
9	5.5	11.78	93.5	37.9	140	6.67	0.39
12	5.5	11.74	93.1	37.9	140	6.68	0.42
15	5.5	11.70	92.8	37.9	141	6.70	0.44
18	5.5	11.65	92.4	37.8	141	6.71	0.40
21	5.4	11.58	91.6	37.7	141	6.72	0.39
24	5.4	11.53	91.2	37.8	142	6.72	0.41
27	5.3	11.48	90.6	37.8	143	6.71	0.34
30	5.3	11.43	90.2	37.8	144	6.69	0.37
33	5.3	11.41	90.1	37.8	146	6.67	0.40
36	5.3	11.36	89.7	37.8	147	6.65	0.44
39	5.3	11.34	89.5	37.8	149	6.63	0.36
42	5.3	11.28	89.0	37.8	150	6.62	0.41
45	5.3	11.26	88.9	37.8	151	6.61	0.40
48	5.3	11.19	88.3	37.8	152	6.59	0.40
49 (Bottom)	5.3	7.97 to 8.74		38.7	75	6.44	3.30

Appendix I-B. March YSI ProDSS profile data for L2 South Basin

Lake Station: L2 South Basin		EMS ID: E315291		Date: 09 - Mar - 20		Time: 12:05 – 12:15	
Parameter							
Depth (m)	Temp Cº	DO (mg/L)	DO % sat (calculated)	SC (µS/cm)	ORP	pH	Turbidity (NTU)
1	5.8	11.90	95.1	33.3	138	6.98	0.67
2	5.7	11.82	94.3	33.3	138	6.94	0.68
3	5.5	11.78	93.5	33.0	137	6.95	0.71
4	5.5	11.75	93.2	33.0	136	6.97	0.69
5	5.4	11.68	92.4	32.7	135	6.97	0.75
6	5.4	11.64	92.1	32.6	136	6.96	0.72
7	5.3	11.60	91.6	32.6	135	6.96	0.81
8	5.3	11.53	91.0	32.5	135	6.93	0.77
9	5.3	11.52	90.9	32.5	135	6.93	0.79
10	5.3	11.50	90.8	32.6	134	6.93	0.86
11	5.2	11.47	90.3	32.6	134	6.92	0.85
12	5.2	11.45	90.1	32.6	135	6.91	0.77
13	5.2	11.45	90.1	32.7	135	6.92	0.80
14	5.2	11.42	89.9	32.7	135	6.90	0.83
15	5.2	11.39	89.7	32.7	136	6.90	0.82
16	5.2	11.38	89.6	32.7	137	6.88	0.80
17	5.2	11.37	89.5	32.7	136	6.90	0.83
18	5.1	11.36	89.2	32.7	137	6.89	0.80
19	5.1	11.36	89.2	32.8	137	6.88	0.89
20	5.1	11.41	89.6	32.8	138	6.86	0.70
21	5.1	11.41	89.6	32.8	138	6.87	0.80
22	5.0	11.37	89.1	32.8	139	6.86	0.90
23	5.1	11.34	89.0	32.9	140	6.84	0.78
24	5.0	11.17	87.5	33.0	138	6.84	34.00

Appendix I-C. March YSI ProDSS profile data for L3 West Arm

Lake Station: L3 West Arm		EMS ID: 1199903		Date: 09 - Mar - 20		Time: 12:05 – 12:15	
Parameter							
Depth (m)	Temp C°	DO (mg/L)	DO % sat (calculated)	SC (µS/cm)	ORP	pH	Turbidity (NTU)
1	5.9	11.89	95.3	43.6	217	6.03	0.37
2	5.9	11.89	95.3	43.6	214	6.06	0.36
3	5.9	11.87	95.1	43.6	209	6.15	0.37
4	5.9	11.86	95.1	43.6	208	6.18	0.39
5	5.9	11.86	95.1	43.6	205	6.23	0.36
6	5.9	11.85	95.0	43.6	205	6.24	0.35
7	5.8	11.79	94.2	43.9	204	6.26	0.37
8	5.8	11.76	94.0	44.2	203	6.27	0.33
9	5.8	11.54	92.3	45.7	203	6.27	0.36
10	5.7	11.27	89.9	46.6	202	6.27	0.35
11	5.7	11.09	88.4	47.8	202	6.28	0.44
12	5.7	10.80	86.1	48.8	202	6.27	0.47
12.5	5.7	7.20	57.4	57.1	134	5.92	1448

Appendix I-D. March YSI ProDSS profile data for L4 North Beach

Lake Station: L4 North Beach		EMS ID: 1199904		Date: 09 - Mar - 20		Time: 12:05 – 12:15	
Parameter							
Depth (m)	Temp Cº	DO (mg/L)	DO % sat (calculated)	SC (µS/cm)	ORP	pH	Turbidity (NTU)
1	5.7	12.43	99.1%	37.7	152	6.93	0.44
2	5.6	12.05	95.8%	37.6	149	6.98	0.47
3	5.5	11.96	94.9%	37.6	148	7.02	0.48
4	5.5	11.93	94.6%	37.6	148	7.06	0.46
5	5.5	11.90	94.4%	37.6	148	7.07	0.42
6	5.5	11.89	94.3%	37.6	150	7.04	0.44
7	5.4	11.87	93.9%	37.5	149	7.06	0.45
8	5.4	11.85	93.8%	37.5	148	7.08	0.45
9	5.4	11.84	93.7%	37.5	146	7.10	0.40
10	5.4	11.83	93.6%	37.5	146	7.11	0.41
11	5.4	11.81	93.5%	37.5	144	7.14	0.41
12	5.4	11.80	93.4%	37.5	145	7.13	0.41
13	5.4	11.79	93.3%	37.5	145	7.12	0.40
14	5.4	11.76	93.1%	37.5	145	7.12	0.39
15	5.4	11.74	92.9%	37.5	145	7.11	0.42
16	5.4	11.73	92.8%	37.5	145	7.12	0.39
17	5.4	11.73	92.8%	37.5	144	7.13	0.43
18	5.4	11.73	92.8%	37.5	144	7.13	0.44
19	5.3	11.74	92.7%	37.6	144	7.13	0.43
20	5.4	10.17	80.5%	41.5	80	6.79	500.00

Appendix I-E. Secchi depth (m) and chlorophyll *a* concentrations at the four lake stations in March and September 2020.

Station	EMS ID	Secchi depth (m)		Chlorophyll *a* µg/L	
		09-Mar-20	**23-Sep-20**	**10-Mar-20**	**25-Sep-20**
L1 North Basin	1199901	3	6.2	2.6	1.14
L2 South Basin	E315291	3	8.16	2.34	1.52
L3 West Arm	1199903	3	7.82	2.01	1.45
L4 North Beach	1199904	3.2	8.04	3.12	1.71

Appendix II-A. September YSI ProDSS profile data for L1 North Basin

Lake Station: L1 North Basin		EMS ID: 1199901		Date: 23 – Sept - 20		Time: 11:15 - !1:45	
Parameter							
Depth (m)	Temp C°	DO (mg/L)	DO % sat (calculated)	SC (µS/cm)	ORP	pH	Turbidity (NTU)
1	19.0	8.92	96.2	65.3	207	6.25	-0.15
3	19.0	8.89	95.9	65.3	194	6.82	-0.19
6	19.0	8.88	95.8	65.4	188	7.01	-0.23
9	12.6	6.32	59.6	61.8	183	6.78	-0.11
12	9.4	5.71	50.0	61.3	183	6.47	-0.06
15	8.4	5.92	50.5	60.6	184	6.37	-0.02
18	7.7	6.66	55.6	60.1	185	6.31	-0.06
21	7.4	6.66	55.5	60.2	184	6.33	-0.06
24	7.2	6.65	55.0	60.3	184	6.32	0.00
27	7.1	6.48	53.6	60.7	185	6.30	0.09
30	7.1	6.39	52.7	60.8	186	6.29	0.12
33	7.0	6.45	53.2	60.7	186	6.29	0.09
36	7.0	6.36	52.4	60.9	186	6.29	0.20
39	7.0	6.13	50.7	61.3	187	6.27	0.25
42	6.9	5.90	48.6	61.7	187	6.26	0.39
45	6.9	5.67	46.7	62.3	188	6.25	0.45
48	6.9	<1.0	8.7	108.1	78	6.41	50 to 400

Appendix II-B. September YSI ProDSS profile data for L2 South Basin

Lake Station: L2 South Basin		EMS ID: E315291		Date: 23 - Sept - 20		Time: 12:50 – 13:18	
Parameter							
Depth (m)	Temp C°	DO (mg/L)	DO % sat (calculated)	SC (µS/cm)	ORP	pH	Turbidity (NTU)
1	19.2	8.53	92.3	65.7	181	6.94	-0.24
2	19.2	8.52	92.2	65.7	179	7.02	-0.19
3	19.2	8.52	92.1	65.7	177	7.08	-0.20
4	19.2	8.51	92.1	65.7	176	7.12	-0.18
5	19.2	8.51	92.0	65.8	174	7.16	-0.20
6	19.2	8.50	92.0	65.8	175	7.16	-0.20
7	18.1	5.94	63.1	64.8	175	6.88	-0.18
8	14.5	4.93	48.4	64.0	174	6.64	-0.14
9	11.5	4.30	39.5	62.6	173	6.48	-0.09
10	9.8	3.67	32.5	62.6	174	6.38	0.06
11	9.0	3.50	30.3	62.3	174	6.35	0.12
12	8.6	3.11	7.1	62.4	174	6.32	0.28
13	8.4	3.00	25.6	62.5	174	6.30	0.36
14	8.2	3.07	26.0	62.3	174	6.31	0.51
15	8.0	2.56	21.7	63.3	174	6.30	1.21
16	8.0	2.51	21.1	63.1	175	6.28	1.21
17	7.9	2.41	20.3	63.1	175	6.28	1.44
18	7.8	2.03	17.1	63.6	175	6.27	2.03
19	7.7	1.77	14.9	63.9	176	6.26	2.40
20	7.6	1.22	10.3	64.6	175	6.25	2.96
21	7.6	0.73	6.1	66.1	176	6.25	3.90
22	7.5	0.45	3.8	67.2	176	6.26	4.50
23	7.5	0.35	2.9	69.7	136	6.24	69.20
24	7.5	0.32	2.7	71.5	106	6.29	452.00

Appendix II-C. September YSI ProDSS profile data for L3 West Arm

Lake Station: L3 West Arm		EMS ID: 1199903		Date: 23 - Sept - 20		Time: 14:00 - 14:16	
Parameter							
Depth (m)	Temp C°	DO (mg/L)	DO % sat (calculated)	SC (µS/cm)	ORP	pH	Turbidity (NTU)
1	19.1	8.76	94.6	66.0	145	7.29	-0.17
2	19.1	8.74	94.5	66.0	146	7.32	-0.12
3	19.1	8.73	94.4	66.0	146	7.33	-0.14
4	19.1	8.72	94.2	66.1	147	7.33	-0.17
5	19.1	8.70	94.0	66.1	147	7.33	-0.16
6	19.1	8.67	93.6	66.1	147	7.33	-0.20
7	18.7	7.25	77.9	66.0	148	7.16	-0.04
8	16.8	3.60	37.5	65.6	151	6.73	0.08
9	14.1	0.55	5.7	72.8	97	6.46	0.37
10	13.1	0.40	3.8	79.9	81	6.45	3.15
11	12.5	0.34	3.2	82.8	64	6.47	3.56
12	12.2	0.31	2.9	86.1	-17	6.42	7.80

Appendix II-D September YSI ProDSS profile data for L4 North Beach

Lake Station: L4 North Basin		EMS ID: 1199904		Date: 23 - Sept - 20		Time: 15:00 – 15:10	
Parameter							
Depth (m)	**Temp Cº**	**DO (mg/L)**	**DO % sat (calculated)**	**SC (µS/cm)**	**ORP**	**pH**	**Turbidity (NTU)**
1	19.0	8.94	96.4%	65.3	61.5	7.45	-0.17
2	19.0	8.93	96.3%	65.3	62.8	7.45	-0.20
3	19.0	8.93	8.9%	65.3	63.8	7.46	-0.18
4	19.0	8.92	96.2%	65.3	64.9	7.46	-0.20
5	19.0	8.91	96.1%	65.3	65.8	7.46	-0.20
6	19.0	8.90	95.9%	65.3	67.0	7.45	-0.15
7	18.9	8.88	95.5%	65.2	67.8	7.45	-0.21
8	16.6	6.45	67.0%	62.5	75.6	7.15	-0.10
9	14.4	6.27	61.4%	63.0	75.6	6.92	-0.05
10	12.2	5.67	53.2%	62.0	83.6	6.73	0.04
11	10.3	5.40	48.2%	61.5	85.6	6.65	0.00
12	9.6	5.36	46.9%	61.4	88.0	6.58	0.06
13	8.7	5.50	47.2%	60.7	90.6	6.54	0.04
14	8.3	5.50	46.8%	60.8	92.4	6.52	0.05
14.5	8.2	5.16	43.8%	61.2	87.2	6.49	10.00

Appendix III-A. Summary of water quality data for water quality station L1 (1199901) North Basin on the two sample dates

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Physical Tests					
Alkalinity – T (as $CaCO_3$)	mg/L	18.6	20.6	23.7	19.0
Hardness (as $CaCO_3$) from total Ca/Mg	mg/L	21.4	21.0	23.8	21.3
Hardness - dissolved	mg/L	20.8	20.1	24.0	22.4
Total suspended solids (TSS)	mg/L	< 3.0*	< 3.0*	< 3.0*	< 3.0*
Anions and Nutrients					
Ammonia – T (as N)	µg/L	< 5.0*	< 5.0*	5.9	6.5
Chloride	mg/L	4.78	1.92	5.10	4.65
Kjeldhal N – T TKN)	µg/L	144	71	173	146
Nitrate N	µg/L	102	36.4	<5.0*	139
Nitrite N	µg/L	<1.0*	<1.0*	<1.0*	<1.0*
Nitrogen - T	µg/L	234	240	174	244
Organic Nitrogen – T	µg/L	143	145	167	140
Phosphate – ortho dis as P	µg/L	<1.0*	<1.0*	<1.0*	<1.0*
Phosphorus - T	µg/L	4.3	3.9	2.4	3.5
Sulfate (as SO_4)	mg/L	2.64	2.77	2.57	2.73
Organic/Inorganic Carbon					
Dissolved organic carbon (DOC)	mg/L	3.47	3.53	3.60	3.25
Total organic carbon (TOC)	mg/L	3.77	3.57	3.72	3.38

* this is the detection limit

Continued on next page

Appendix III-A continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals – Total					
Aluminum – T	mg/L	0.052	0.0477	0.0085	0.0183
Antimony – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Arsenic – T	mg/L	0.00015	0.00013	0.00018	0.00012
Barium – T	mg/L	0.00511	0.00494	0.00517	0.00547
Beryllium – T	mg/L	<0.000100*	<0.000100*	<0.000100*	<0.000100*
Bismuth - T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Boron – T	mg/L	<0.010*	<0.010*	<0.010*	<0.010*
Cadmium – T	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Calcium – T	mg/L	6.51	6.39	7.26	6.55
Cesium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Chromium – T	mg/L	0.00014	0.00012	<0.00010*	0.00014
Cobalt -T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Copper – T	mg/L	0.00081	0.00069	0.00118	0.00074
Iron – T	mg/L	0.037	0.041	0.026	0.075
Lead – T	mg/L	0.000167	<0.000050*	<0.000050*	<0.000050*
Lithium – T	mg/L	<0.0010*	<0.0010*	<0.0010*	<0.0010*
Magnesium – T	mg/L	1.26	1.24	1.38	1.20
Manganese -T	mg/L	0.00257	0.00368	0.00658	0.172
Mercury – T	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Molybdenum – T	mg/L	0.000074	0.000071	0.000095	0.000068
Nickel – T	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.0000050*
Potassium – T	mg/L	0.300	0.276	0.265	0.270
Rubidium – T	mg/L	0.00028	0.00027	0.00027	0.00029
Selenium – T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*

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Appendix III-A continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals – Total continued					
Silicon – T	mg/L	2.52	2.56	1.77	2.98
Silver - T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Sodium – T	mg/L	3.36	3.10	3.58	3.39
Strontium – T	mg/L	0.0248	0.0235	0.0297	0.0286
Sulfur – T	mg/L	0.87	0.90	0.72	0.50
Tellurium – T	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*
Thallium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Thorium – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Tin – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Titanium – T	mg/L	0.00267	0.00095	<0.00030*	<0.00030*
Tungsten – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Uranium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Vanadium – T	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.00050*
Zinc – T	mg/L	<0.0030*	<0.0030*	<0.0030*	<0.0030*
Zirconium – T	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*

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Appendix III-A cont. (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals - dissolved					
Aluminum – dis	mg/L	0.0276	0.0260	0.0052	0.0138
Antimony – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Arsenic – dis	mg/L	0.00012	0.00011	0.00019	0.00014
Barium – dis	mg/L	0.00476	0.00475	0.00542	0.00612
Beryllium – dis	mg/L	<0.000100*	<0.000100*	<0.000100*	<0.000100*
Bismuth - dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Boron – dis	mg/L	<0.010*	<0.010*	<0.010*	<0.010*
Cadmium – dis	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Calcium – dis	mg/L	6.29	6.18	7.39	6.90
Cesium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Chromium – dis	mg/L	<0.00010*	0.00013	<0.00010*	0.00014
Cobalt - dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Copper – dis	mg/L	0.00068	0.00061	0.00092	0.00069
Iron – dis	mg/L	0.014	0.014	0.010	0.030
Lead – dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Lithium – dis	mg/L	<0.0010*	<0.0010*	<0.0010*	<0.0010*
Magnesium – dis	mg/L	1.23	1.14	1.36	1.25
Manganese -dis	mg/L	0.00023	0.00072	0.00034	0.151
Mercury – dis	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Molybdenum – dis	mg/L	0.000066	0.000069	0.000068	0.000080
Nickel – dis	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.0000050*
Potassium – dis	mg/L	0.300	0.273	0.311	0.324
Rubidium – dis	mg/L	0.00026	0.00027	0.00027	0.00029
Selenium – dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*

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Appendix III-A Continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals – Dissolved continued					
Silicon – dis	mg/L	2.49	2.50	1.78	2.86
Silver - dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Sodium – dis	mg/L	3.24	3.24	3.51	3.27
Strontium – dis	mg/L	0.0251	0.0272	0.0300	0.0273
Sulfur – dis	mg/L	0.91	0.70	0.95	0.86
Tellurium – dis	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*
Thallium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Thorium – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Tin – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Titanium – dis	mg/L	<0.00030*	<0.00010*	<0.00030*	<0.00030*
Tungsten – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Uranium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Vanadium – dis	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.00050*
Zinc – dis	mg/L	<0.0030*	0.0027	<0.0030*	<0.0030*
Zirconium – dis	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*

Appendix III-B Summary of water quality data for water quality station L2 (E315291) South Basin on the two sample dates.

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Physical Tests					
Alkalinity – T (as $CaCO_3$)	mg/L	14.9	15.3	19.8	18.7
Hardness (as $CaCO_3$) from total Ca/Mg	mg/L	21.4	17.9	23.9	23.4
Hardness - dissolved	mg/L	17.9	17.9	23.9	22.7
Total suspended solids (TSS)	mg/L	< 3.0*	< 3.0*	< 3.0*	< 3.0*
Anions and Nutrients					
Ammonia – T (as N)	µg/L	< 5.0*	< 5.0*	20.3	24.2
Chloride	mg/L	4.49	4.53	5.28	5.45
Kjeldhal N – T TKN)	µg/L	147	117	167	165
Nitrate N	µg/L	90.4	94.6	<5.0*	122
Nitrite N	µg/L	<1.0*	<1.0*	<1.0*	<1.0*
Nitrogen - T	µg/L	216	213	180	269
Organic Nitrogen – T	µg/L	146	116	146	141
Phosphate – ortho dis as P	µg/L	<1.0*	1.4	<1.0*	2.6
Phosphorus - T	µg/L	4.5	5.4	9.9	2.9
Sulfate (as SO_4)	mg/L	2.71	2.82	2.54	2.58
Organic/Inorganic Carbon					
Dissolved organic carbon (DOC)	mg/L	3.42	3.38	3.77	3.39
Total organic carbon (TOC)	mg/L	3.70	3.54	3.68	3.79

* this is the detection limit

Continued on next page

Appendix III-B continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals - Total					
Aluminum – T	mg/L	0.0790	0.0884	0.0078	0.0350
Antimony – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Arsenic – T	mg/L	0.00012	0.00011	0.00019	0.00020
Barium – T	mg/L	0.00392	0.00402	0.00521	0.00680
Beryllium – T	mg/L	<0.000100*	<0.000100*	<0.000100*	<0.000100*
Bismuth - T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Boron – T	mg/L	<0.010*	<0.010*	<0.010*	<0.010*
Cadmium – T	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Calcium – T	mg/L	5.31	5.46	7.23	7.18
Cesium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Chromium – T	mg/L	0.00034	0.00020	<0.00010*	0.00013
Cobalt -T	mg/L	<0.00010*	<0.00010*	<0.00010*	0.00030
Copper – T	mg/L	0.00074	0.00067	0.00085	0.00070
Iron – T	mg/L	0/068	0.082	0.030	0.747
Lead – T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Lithium – T	mg/L	<0.0010*	<0.0010*	<0.0010*	<0.0010*
Magnesium – T	mg/L	1.13	1.15	1.41	1.32
Manganese -T	mg/L	0.00340	0.00528	0.00508	0.188
Mercury – T	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Molybdenum – T	mg/L	0.000062	0.000058	0.000074	0.000077
Nickel – T	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.0000050*
Potassium – T	mg/L	0.267	0.250	0.272	0.299
Rubidium – T	mg/L	0.00030	0.00031	0.00029	0.00032
Selenium – T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*

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Appendix III-B continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals – Total continued					
Silicon – T	mg/L	2.72	2.92	1.80	3.01
Silver - T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Sodium – T	mg/L	3.16	3.07	3.62	3.67
Strontium – T	mg/L	0.0220	0.0228	0.0312	0.0340
Sulfur – T	mg/L	0.94	0.89	0.69	0.69
Tellurium – T	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*
Thallium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Thorium – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Tin – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Titanium – T	mg/L	0.00201	0.00226	<0.00030*	<0.00030*
Tungsten – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Uranium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Vanadium – T	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.00050*
Zinc – T	mg/L	<0.0030*	<0.0030*	<0.0030*	<0.0030*
Zirconium – T	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*

Continued on next page

Appendix III-B continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals - dissolved					
Aluminum – dis	mg/L	0.0457	0.0541	0.0052	0.0258
Antimony – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Arsenic – dis	mg/L	<0.00010*	<0.00010*	0.00020	0.00020
Barium – dis	mg/L	0.00365	0.00359	0.00531	0.00661
Beryllium – dis	mg/L	<0.000100*	<0.000100*	<0.000100*	<0.000100*
Bismuth - dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Boron – dis	mg/L	<0.010*	<0.010*	<0.010*	<0.010*
Cadmium – dis	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Calcium – dis	mg/L	5.36	5.30	7.41	7.03
Cesium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Chromium – dis	mg/L	0.00012	0.00014	<0.00010*	0.00012
Cobalt - dis	mg/L	<0.00010*	<0.00010*	<0.00010*	0.00024
Copper – dis	mg/L	0.00064	0.00062	0.00061	0.00060
Iron – dis	mg/L	0.027	0.047	0.014	0.481
Lead – dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Lithium – dis	mg/L	<0.0010*	<0.0010*	<0.0010*	<0.0010*
Magnesium – dis	mg/L	1.10	1.13	1.32	1.25
Manganese -dis	mg/L	0.00126	0.00277	0.00068	0.184
Mercury – dis	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Molybdenum – dis	mg/L	0.000059	<0.000050*	0.000081	0.000060
Nickel – dis	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.0000050*
Potassium – dis	mg/L	0.262	0.254	0.298	0.321
Rubidium – dis	mg/L	0.00026	0.00022	0.00028	0.00036
Selenium – dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*

Continued on next page

Appendix III-B continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals – dissolved continued					
Silicon – dis	mg/L	2.68	2.84	1.75	2.94
Silver - dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Sodium – dis	mg/L	3.16	3.17	3.58	3.55
Strontium – dis	mg/L	0.0228	0.0236	0.0328	0.338
Sulfur – dis	mg/L	0.78	0.80	0.84	0.87
Tellurium – dis	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*
Thallium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Thorium – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Tin – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Titanium – dis	mg/L	0.00060	0.00093	<0.00030*	0.00041
Tungsten – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Uranium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Vanadium – dis	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.00050*
Zinc – dis	mg/L	<0.0030*	0.0025	<0.0030*	0.0015
Zirconium – dis	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*

Appendix III-C. Summary of water quality data for water quality station L3 (1199903) West Arm on the two sample dates.

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Physical Tests					
Alkalinity – T (as $CaCO_3$)	mg/L	22.1	25.6	20.6	24.8
Hardness (as $CaCO_3$) from total Ca/Mg	mg/L	25.2	28.9	24.2	28.7
Hardness - dissolved	mg/L	25.0	28.4	24.4	27.4
Total suspended solids (TSS)	mg/L	< 3.0*	< 3.0*	< 3.0*	< 3.0*
Anions and Nutrients					
Ammonia – T (as N)	µg/L	< 5.0*	< 5.0*	< 5.0*	0.0214
Chloride	mg/L	5.23	5.52	5.18	4.78
Kjeldhal N – T TKN)	µg/L	154	157	185	292
Nitrate N	µg/L	98.4	112	<5.0*	<5.0*
Nitrite N	µg/L	<1.0*	<1.0*	<1.0*	<1.0*
Nitrogen - T	µg/L	243	263	168	238
Organic Nitrogen – T	µg/L	153	153	183	270
Phosphate – ortho dis as P	µg/L	<1.0*	<1.0*	<1.0*	<1.0*
Phosphorus - T	µg/L	5.0	5.1	2.9	9.6
Sulfate (as SO_4)	mg/L	2.66	2.65	2.58	2.27
Organic/Inorganic Carbon					
Dissolved organic carbon (DOC)	mg/L	3.47	3.46	3.76	4.12
Total organic carbon (TOC)	mg/L	4.02	3.56	3.79	4.29

* this is the detection limit

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Appendix III-C continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals - Total					
Aluminum – T	mg/L	0.0383	0.0432	0.0068	0.0230
Antimony – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Arsenic – T	mg/L	0.00012	0.00012	0.00019	0.00034
Barium – T	mg/L	0.00559	0.00601	0.00540	0.00984
Beryllium – T	mg/L	<0.000100*	<0.000100*	<0.000100*	<0.000100*
Bismuth - T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Boron – T	mg/L	<0.010*	<0.010*	<0.010*	<0.010*
Cadmium – T	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Calcium – T	mg/L	7.9	9.22	7.37	9.18
Cesium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Chromium – T	mg/L	0.00012	0.00014	<0.00010*	0.00014
Cobalt -T	mg/L	<0.00010*	<0.00010*	<0.00010*	0.00044
Copper – T	mg/L	0.00070	0.00075	0.00076	0.00074
Iron – T	mg/L	0.035	0.047	0.035	1.95
Lead – T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Lithium – T	mg/L	<0.0010*	<0.0010*	<0.0010*	<0.0010*
Magnesium – T	mg/L	1.32	1.42	1.40	1.40
Manganese -T	mg/L	0.00311	0.00497	0.00993	0.477
Mercury – T	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Molybdenum – T	mg/L	0.000062	0.000060	0.000069	0.000098
Nickel – T	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.0000050*
Potassium – T	mg/L	0.304	0.298	0.280	0.346
Rubidium – T	mg/L	0.00026	0.00024	0.00031	0.00038
Selenium – T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*

Continued on next page

Appendix III-C continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals – Total continued					
Silicon – T	mg/L	2.61	2.96	1.74	2.24
Silver - T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Sodium – T	mg/L	3.42	3.64	3.64	3.30
Strontium – T	mg/L	0.0272	0.0306	0.0306	0.0355
Sulfur – T	mg/L	0.84	0.82	0.72	0.52
Tellurium – T	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*
Thallium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Thorium – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Tin – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Titanium – T	mg/L	0.00267	0.00095	<0.00030*	<0.00030*
Tungsten – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Uranium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Vanadium – T	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.00050*
Zinc – T	mg/L	<0.0030*	<0.0030*	<0.0030*	<0.0030*
Zirconium – T	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*

Continued on next page

Appendix III-C continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals - dissolved					
Aluminum – dis	mg/L	0.0258	0.0282	0.0041	0.0136
Antimony – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Arsenic – dis	mg/L	0.00012	0.00012	0.00018	0.00033
Barium – dis	mg/L	0.00546	0.00588	0.00535	0.00758
Beryllium – dis	mg/L	<0.000100*	<0.000100*	<0.000100*	<0.000100*
Bismuth - dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Boron – dis	mg/L	<0.010*	<0.010*	<0.010*	<0.010*
Cadmium – dis	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Calcium – dis	mg/L	7.84	9.08	7.52	8.80
Cesium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Chromium – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	0.00011
Cobalt - dis	mg/L	<0.00010*	<0.00010*	<0.00010*	0.00042
Copper – dis	mg/L	0.00066	0.00066	0.00059	0.00038
Iron – dis	mg/L	0.019	0.027	0.014	1.46
Lead – dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Lithium – dis	mg/L	<0.0010*	<0.0010*	<0.0010*	<0.0010*
Magnesium – dis	mg/L	1.32	1.40	1.35	1.32
Manganese -dis	mg/L	0.00094	0.00214	0.00041	0.486
Mercury – dis	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Molybdenum – dis	mg/L	0.000052	0.000061	0.000069	0.000077
Nickel – dis	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.0000050*
Potassium – dis	mg/L	0.302	0.300	0.303	0.360
Rubidium – dis	mg/L	0.00023	0.00023	0.00027	0.00038
Selenium – dis	mg/L	<0.000050*	<0.000050*	<0.000050*	0.000052

Continued on next page

Appendix III-C continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals – Dissolved continued					
Silicon – dis	mg/L	2.58	2.90	1.76	2.18
Silver - dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Sodium – dis	mg/L	3.54	3.68	3.45	3.23
Strontium – dis	mg/L	0.0278	0.0310	0.0296	0.0332
Sulfur – dis	mg/L	0.78	0.80	0.81	0.77
Tellurium – dis	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*
Thallium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Thorium – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Tin – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Titanium – dis	mg/L	<0.00030*	0.00030	<0.00030*	<0.00030*
Tungsten – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Uranium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Vanadium – dis	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.00050*
Zinc – dis	mg/L	0.0016	0.0017	<0.0030*	0.0019
Zirconium – dis	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*

Appendix III-D Summary of water quality data for water quality station L4 (1199904) North Beach on the two sample dates

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Physical Tests					
Alkalinity – T (as $CaCO_3$)	mg/L	18.0	18.0	20.1	18.5
Hardness (as $CaCO_3$) from total Ca/Mg	mg/L	20.7	21.3	24.0	22.7
Hardness - dissolved	mg/L	20.4	20.4	23.6	22.1
Total suspended solids (TSS)	mg/L	< 3.0*	< 3.0*	< 3.0*	< 3.0*
Anions and Nutrients					
Ammonia – T (as N)	µg/L	< 5.0*	< 5.0*	7.5	< 5.0*
Chloride	mg/L	4.75	4.75	5.15	4.67
Kjeldhal N – T TKN)	µg/L	139	140	195	125
Nitrate N	µg/L	102	102	<5.0*	51.2
Nitrite N	µg/L	<1.0*	<1.0*	<1.0*	<1.0*
Nitrogen - T	µg/L	234	232	175	149
Organic Nitrogen – T	µg/L	138	140	188	121
Phosphate – ortho dis as P	µg/L	<1.0*	<1.0*	<1.0*	<1.0*
Phosphorus - T	µg/L	4.4	5.0	2.7	5.6
Sulfate (as SO_4)	mg/L	2.65	2.64	2.57	2.84
Organic/Inorganic Carbon					
Dissolved organic carbon (DOC)	mg/L	3.36	3.43	3.78	3.30
Total organic carbon (TOC)	mg/L	3.80	3.66	3.77	3.53

* this is the detection limit

Continued on next page

Appendix III-D continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals - Total					
Aluminum – T	mg/L	0.0461	0.0468	0.0080	0.0241
Antimony – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Arsenic – T	mg/L	0.00013	0.00013	0.00018	0.00010
Barium – T	mg/L	0.00488	0.00502	0.00523	0.00558
Beryllium – T	mg/L	<0.000100*	<0.000100*	<0.000100*	<0.000100*
Bismuth - T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Boron – T	mg/L	<0.010*	<0.010*	<0.010*	<0.010*
Cadmium – T	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Calcium – T	mg/L	6.27	6.56	7.32	6.94
Cesium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Chromium – T	mg/L	0.00012	0.00013	<0.00010*	0.00014
Cobalt -T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Copper – T	mg/L	0.00076	0.00072	0.00537	0.00067
Iron – T	mg/L	0.037	0.040	0.031	0.038
Lead – T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Lithium – T	mg/L	<0.0010*	<0.0010*	<0.0010*	<0.0010*
Magnesium – T	mg/L	1.22	1.21	1.39	1.31
Manganese -T	mg/L	0.00272	0.00270	0.00587	0.0660
Mercury – T	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Molybdenum – T	mg/L	0.000062	0.000103	0.000117	0.000060
Nickel – T	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.0000050*
Potassium – T	mg/L	0.286	0.291	0.289	0.303
Rubidium – T	mg/L	0.00027	0.00025	0.00029	0.00029
Selenium – T	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*

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Appendix III-D continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals – Total continued					
Silicon – T	mg/L	2.52	2.48	1.75	2.61
Silver - T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Sodium – T	mg/L	3.20	3.14	3.62	3.34
Strontium – T	mg/L	0.0244	0.0247	0.0302	0.0280
Sulfur – T	mg/L	0.85	0.90	0.78	0.83
Tellurium – T	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*
Thallium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Thorium – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Tin – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Titanium – T	mg/L	0.00267	0.00095	<0.00030*	<0.00030*
Tungsten – T	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Uranium – T	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Vanadium – T	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.00050*
Zinc – T	mg/L	<0.0030*	<0.0030*	<0.0030*	<0.0030*
Zirconium – T	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*

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Appendix III-D continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals - dissolved					
Aluminum – dis	mg/L	0.0261	0.0246	0.0050	0.0153
Antimony – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Arsenic – dis	mg/L	0.00011	0.00012	0.00018	0.00014
Barium – dis	mg/L	0.00482	0.00459	0.00534	0.00539
Beryllium – dis	mg/L	<0.000100*	<0.000100*	<0.000100*	<0.000100*
Bismuth - dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Boron – dis	mg/L	<0.010*	<0.010*	<0.010*	<0.010*
Cadmium – dis	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Calcium – dis	mg/L	6.19	6.20	7.27	6.80
Cesium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Chromium – dis	mg/L	0.00012	0.00013	<0.00010*	0.00014
Cobalt - dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Copper – dis	mg/L	0.00063	0.00064	0.00063	0.00057
Iron – dis	mg/L	0.014	0.013	<0.010*	0.015
Lead – dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*
Lithium – dis	mg/L	<0.0010*	<0.0010*	<0.0010*	<0.0010*
Magnesium – dis	mg/L	1.20	1.20	1.32	1.24
Manganese -dis	mg/L	0.00025	0.00026	0.00039	0.0364
Mercury – dis	mg/L	<0.0000050*	<0.0000050*	<0.0000050*	<0.0000050*
Molybdenum – dis	mg/L	0.000057	0.000057	0.000062	0.000066
Nickel – dis	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.0000050*
Potassium – dis	mg/L	0.294	0.291	0.297	0.325
Rubidium – dis	mg/L	0.00024	0.00024	0.00025	0.00028
Selenium – dis	mg/L	<0.000050*	<0.000050*	<0.000050*	<0.000050*

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Appendix III-D continued (* is the detection limit)

Parameter	Units	March 10, 2020		September 25, 2020	
		Top	Bottom	Top	Bottom
Metals – Dissolved continued					
Silicon – dis	mg/L	2.42	2.38	1.70	2.56
Silver - dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Sodium – dis	mg/L	3.22	3.24	3.44	3.16
Strontium – dis	mg/L	0.0248	0.0248	0.0294	0.0279
Sulfur – dis	mg/L	0.78	0.76	0.86	0.97
Tellurium – dis	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*
Thallium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Thorium – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Tin – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Titanium – dis	mg/L	<0.00030*	0.00095	<0.00030*	<0.00030*
Tungsten – dis	mg/L	<0.00010*	<0.00010*	<0.00010*	<0.00010*
Uranium – dis	mg/L	<0.000010*	<0.000010*	<0.000010*	<0.000010*
Vanadium – dis	mg/L	<0.00050*	<0.00050*	<0.00050*	<0.00050*
Zinc – dis	mg/L	0.0025	0.0014	<0.0030*	0.0015
Zirconium – dis	mg/L	<0.00020*	<0.00020*	<0.00020*	<0.00020*

Appendix IV Contaminated Soil Landfill on Lot 23

Brief History: South Island Aggregates (SIA) operated a quarry on Lot 23, owned by Cobble Hill Holdings (CHH) since 2006. On October 2010, highly toxic soil containing perchloroethylene (PERC) was dumped onto Lot 21, a property also owned by CHH that is located immediately north of Lot 23. SIA/CHH in conjunction with Active Earth Engineering (AEE) determined that the solution to this illegal dumping of toxic soil onto Lot 21 was to obtain a contaminated soil landfill permit. ENV agreed and issued Permit 105809 to SIA on April 21, 2013. The Permit was subsequently transferred to CHH. There was objection from the public and the CVRD and the case was brought before the Environmental Appeal Board (EAB) who ultimately upheld the Permit. At this point SIA/CHH worked with Allterra Construction Ltd to operate the contaminated soil landfilling operation. Allterra created South Island Resource Management (SIRM) to oversee the contaminated soil landfilling operation.

Understandably the citizens of the Shawnigan Lake area vehemently objected since Upper Shawnigan Creek runs through Lot 23 and Shawnigan Lake is 4.9 kilometres directly downhill of Lot 23 as can be seen in Figure 1.

Figure 1. Shawnigan Lake. Photo taken from the south-west corner of Lot 23.

Both the CVRD and the Shawnigan Residents Association (SRA) filed court cases, the CVRD lost their case based upon zoning while the SRA ultimately won their case when Justice Sewell rendered his verdict on

January 24, 2017. In essence he stated that because there was a secrete agreement between AEE and SIA/CHH to share profits, there was no arms-length relationship between SIA/CHH and AEE. This fact was hidden from the EAB; hence, the EAB decision to uphold the permit was set aside and the EAB must reconsider its decision to uphold the Permit. On January 27, 2017, the Province suspended the Permit and on February 23, 2017, the Province cancelled the permit. The reason, as stated in the letter from Minister Polak, was that there was inadequate security set aside for the final closure plan and for post-closure costs. It is likely that without the huge public outcry, the Permit would not have been pulled and the Shawnigan Lake watershed would have eventually contained ten million tonnes of contaminated soil located uphill of Shawnigan Lake as allowed by the Permit.

Contaminated Soil Landfill: While the Permit was still valid, according to records, a total of 97,595 tonnes of contaminated soil was brought onto the site, i.e., 1% of what the Permit had allowed. Much of the contaminated soil was ocean dredgeate with major contaminants being sodium and chloride. Another major contaminant was elemental sulfur. We estimate approximately 5,000 tonnes of elemental sulfur was deposited into the PEA. The concern with elemental sulfur is that soil microorganisms can convert it to sulfuric acid; however, this requires oxygen and the PEA should be anaerobic.

From June 2016 onwards when the 'B' and 'C' parts of the PEA were constructed, the landfilling operation was continually monitored by members of the Shawnigan Research Group, most of whom are now Directors of the Shawnigan Basin Society. Many flaws in the design and operation of the contaminated soil landfilling operation were observed and many futile meetings with Ministry personnel were held. The design flaws ensured that the landfill would leak. Indeed, from data collected by ENV we know that the site is leaking. One example is indicated by Figure 2 that shows the change in sodium and chloride ion levels between 2015 and 2019 in Monitoring Well 3S. Fortunately, although a slow rise in sodium and chloride was observed in monitoring wells, they are still well below any level of concern.

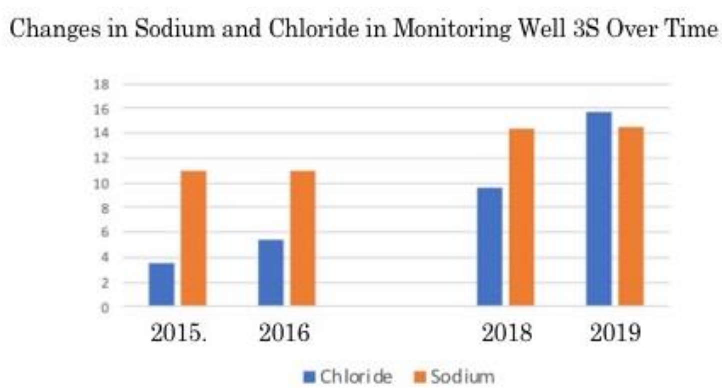

Figure 2. Graph demonstrating rising levels of chloride and sodium in Monitoring Well 3S. Because of the overall charge of soil and till is negative, there is more rapid movement of negatively charged chloride ions than the positively charged sodium ions. Data obtained from ENV's website.

Final Closure Plan: The Final Closure Plan was approved by Minister Heyman on June 26, 2019. This Plan was devised by Sperling Hansen Associates (SHA), who at the time was owed $100,000 by CHH. The Final Closure Plan included bringing in an additional 70,000 tonnes of 'clean' fill, thus generating income for the Named Parties. Strangely, that CHH owed SHA a considerable sum of money and the Final Closure Plan allowed more fill intake thereby generating funds was not deemed a conflict by ENV.

The Final Closure Plan included the remaining 3,360 tonnes of contaminated soil in the Soil Management Area (SMA) being discharged into the PEA. Sealing the surface of the PEA with liner and bringing in an additional 70,000 tonnes of 'clean' fill. Much of this was placed upon the northerly and easterly slopes of the PEA generating an approximately 5H:1V slope. The minimum amount of fill covering the liner is 1.5 metres, on top of which is to be placed 0.5 metres of topsoil. This topsoil is to be hydroseeded and planted with trees. In addition, the Final Closure Plan included several more monitoring wells being drilled. The Final Closure Plan is now almost completed except for the planting of trees and the continual monitoring of the site.

Post-Closure Monitoring: The Final Closure Plan includes monitoring the site over a 30 year period. The Post-Closure activities includes quarterly monitoring of the new monitoring wells MW 19-1 and MW 19-2. At the insistence of the Shawnigan Research Group ENV mandated that monitoring well MW 3S also be monitored quarterly since this will demonstrate potential changes to the groundwater. In addition, there will be quarterly monitoring of Seepage Blanket Wells SB-1, SB-2, SB-3 and SB-4. For the first post-closure year there will be monthly monitoring of the Ephemeral Stream, quarterly monitoring in Year 2 and then semi-annual monitoring. Leachate volume will be monitored daily and leachate collected as needed. Initially, there will be quarterly reports and this will decrease in frequency with time.

Concluding Remarks: Without the outcry of the citizenry, the Shawnigan Lake watershed would have contained millions of tonnes of contaminated soil situated directly above Shawnigan Lake on a site through which Upper Shawnigan Creek runs. The failure of ENV to protect the Shawnigan Lake watershed is criminal in nature. Fortunately, fewer than 100,000 tonnes of contaminated soil ended up in the Lot 23 landfill. The other fortunate thing is that the major contaminants present in the soil were sodium and chloride ions. Slow leaching of these ions will likely have little impact on the watershed and underlying groundwater. The elemental sulfur present in the landfill likely will not give rise to significant sulfuric acid because of the anaerobic nature of the landfill. No soil was known to be deposited with other allowable contaminants such as the carcinogenic dioxins.

Without the outcry by the people of South Cowichan the ecological health of the Shawnigan watershed would likely have been destroyed.